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Can Urban Local Ponds Help Tackle Domestic Water Scarcity and Build Resilience?

with Reference to South Asian Cities and City Regions

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Abstract. *For decades to come, cost-effective and environmentally appropriate water systems will be a priority for managing water scarcity and building resilience in the rapidly expanding cities and city regions of South Asia. This study initiates a research into urban local ponds and the potential of linking them with water systems and build resilience. A framework of questions guided the research with reference to ponds and prevalent water systems in South Asian cities and city regions. The wider issues of water stress in South Asian cities and the general limitations of prevalent water supply systems were studied through the lens of a literature review. The paper then draws upon observations in three South Asian cities. The research showed that despite policy support for local rainwater capture, groundwater is over-exploited and urban local ponds (and tanks) have not been integrated with urban water provision schemes, particularly in recent decades. It was concluded that local urban ponds can facilitate resilient water-supply provision by making them an integral part of the urban waterscape. This paper highlights a multitude of benefits that ponds can potentially bring to urban resilience, in particular affordable and accessible water provision with low environmental footprint, managing climate shocks or stresses, biodiversity restoration in urban areas as well as potentially generating new skills and livelihoods for communities. The overall suggestion is that local urban ponds should be networked into the water provision for cities and their wider region, thereby linking to wider arrangements for urban and regional governance and resilience.*

Keywords. *Ponds, urban resilience, surface water, water networks, water governance, regional water transfer.*

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Abstrak. *Dalam beberapa dekade mendatang, sistem air yang hemat biaya dan ramah lingkungan akan menjadi prioritas untuk mengelola kelangkaan air dan membangun ketangguhan di kota-kota yang berkembang pesat dan kawasan perkotaan di Asia Selatan. Makalah ini memulai penelitian mengenai kolam lokal perkotaan, dan potensi untuk menghubungkannya dengan sistem air dan membangun ketangguhan. Kerangka pertanyaan memandu penelitian ini dengan mengacu pada kolam dan sistem air yang umum di kota-kota Asia Selatan dan kawasan kota. Isu yang lebih luas mengenai persoalan air di kota-kota Asia Selatan dan keterbatasan sistem penyediaan air yang umum dipelajari melalui tinjauan literatur. Makalah ini kemudian mengacu pada pengamatan di tiga kota di Asia Selatan. Penelitian menunjukkan bahwa meskipun ada dukungan kebijakan untuk penangkapan air hujan lokal, air tanah dieksploitasi secara berlebihan dan kolam lokal perkotaan (dan tangki) tidak terintegrasi dengan skema penyediaan air perkotaan, terutama dalam beberapa dekade terakhir. Disimpulkan bahwa kolam lokal perkotaan dapat memfasilitasi penyediaan pasokan air yang tangguh dengan menjadikannya*

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sebagai bagian integral dari lanskap perairan perkotaan. Makalah ini menunjukkan bahwa banyak potensi manfaat kolam untuk ketangguhan perkotaan, khususnya dalam penyediaan air yang terjangkau dan dapat diakses dengan jejak lingkungan yang rendah, mengelola gegar atau tekanan iklim, pemulihan keanekaragaman hayati di daerah perkotaan serta berpotensi menghasilkan keterampilan dan mata pencaharian baru bagi masyarakat. Saran keseluruhan adalah bahwa kolam lokal perkotaan harus disambungkan ke dalam sistem penyediaan air untuk kota dan wilayah yang lebih luas, sehingga menghubungkannya dengan pengaturan yang lebih luas untuk tata kelola dan ketangguhan perkotaan dan regional.

Kata kunci. *Kolam, ketangguhan perkotaan, air permukaan, jaringan air, tata kelola air, transfer air regional.*

Introduction: Initiating Research into Urban Local Ponds

Walking through major cities of South Asia such as Khulna (Bangladesh), Chennai (India) and Kathmandu (Nepal) it is hard, not to be hit by the inherent contradiction between the reports of crippling freshwater scarcity in these cities and the ubiquitous natural and artificial ponds and tanks that meet the eye in almost every direction one looks, within as well as beyond the municipal limits. A closer look at ponds for enhancing water system resilience is time-critical, as rapid urbanisation is diminishing these precious water reserves. The news is not all bad; ponds as ecological features are getting protected status in some locations within the domain of eco-system services. As recently as March 2020, the High court of Punjab and Haryana in India ruled that Sukhna reservoir is a ‘living’ entity and has the same protection rights as a human.

Recent studies on urban water provision in South Asia show that although policy measures for local rainwater capture are in place for many cities, groundwater water resources still tend to be over-exploited (Escurra Aguirre & Jones, 2019; Roth et al., 2019; Vinke et al., 2017). The importance of urban local ponds for urban water management is acknowledged (e.g., Yazdi, 2019), but their role is generally poorly understood in the Global South (e.g., Cornea et al., 2016). Human activity, prosperity and resilience are dependent upon freshwater ecosystems comprising lakes, rivers, aquifers, marshes and other wetlands, and the services they provide. It is assumed that preserving these must be a central development aim (Boltz et al., 2019). Intrigued by these observations, this study set off to initiate research into urban local ponds, seeking to better investigate the untapped potential of ponds and their role within fresh water provision choices and systems in order to reduce water scarcity and reinforce resilience in the rapidly expanding cities of South Asia.

Resilience is often related to the duration during which a system or its components regain functionality in providing a service (e.g., Folke et al, 2005). To ensure reliability and continuity of a critical service such as water, the capture and storage of rainwater in urban regions are widely prioritised in urban and city resilience strategies (Tyler and Moench 2012; Butler et al, 2014). Rainwater capture for domestic water use is an age-old practice and such water systems can range from single households and small communities, small surface reservoir systems to large surface dam systems. Each has unique design, operation and governance requirements (Johnston and McCartney 2010). Authors like Blackmore (2008), Ahern (2011), and Wagner and Briel (2013) have proposed design frameworks for urban resilience, where hydrological or ecological components such as surface water reservoirs are integrated or interconnected within the urban water system. Such an urban ‘eco-hydrology’, according to Wagner and Briel (2013, p131), will turn ecological features such as ponds into ‘tools’ for integrated urban water resources management and “*provide an alternative background for city managers to include natural water* *bodies inside the global urban water cycle. It applies mostly to the natural- or stormwater-fed urban aquatic ecosystems, constructed water systems (e.g., reservoirs, wetlands, sedimentary systems) ...”* In a major and critical service such as water supply, the use of decentralised components (such as small reservoirs and ponds) has been seen to enhance resilience towards disruption. (Hwang et al., 2014)

The following framework of questions guided the research for this paper with reference to ponds and prevalent water systems in South Asian cities and city regions. The first two questions relate to the wider issues of water stress in South Asian cities and the general limitations of prevalent water supply systems and were studied through the lens of a literature review:

- What is the acknowledged scale of water stress in South Asian cities?
- What are some of the climate, environmental, financial and social limitations of the ways in which cities and city regions are currently supplying freshwater?

The study then used empirical observations in Khulna (Bangladesh), Chennai (India) and Kathmandu (Nepal) to look at the specific situation in each of these cities. The three cities were selected as the author had visited them between 2016 and 2019. The cities are widely known to suffer from water scarcity while surface water bodies are aplenty in these cities, thus offering the coincidence necessary to respond to the research questions. Two of these three cities are in coastal regions, with the additional issue of salinity intrusion into groundwater. The key questions in the case studies were as follows:

1. Are there sufficient provisions in existing policies and systems to capture rainwater for domestic water provision?
2. What are the current uses and conditions of urban ponds and wetlands?
3. Are urban ponds linked to the current water system in the city?
4. Is there potential for using urban ponds to reduce domestic water stress whilst minimising the adverse environmental impacts of the current water provision choices?
5. Do they have wider resilience benefits such as for ecosystem restoration?
6. What further research and data related to technical and governance issues can be promoted to enable the integration of ponds within water provision systems?

Systematic data and studies from traditional sources on the ponds in these cities are scarce. Therefore to elaborate on the case specific questions, observations were drawn from a mix of sources, including publicly available reports published by local, state and national authorities or from ongoing water supply projects; conference proceedings and studies in local research or teaching institutions; discussions with specialists with knowledge of the local context, relevant observations reported in the media; and the authors’ own observations during visits to the cities. These processes of data collection and observations were undertaken between 2016 and 2019. Evidence from the cases, their contexts and relevant policy frameworks are discussed thematically in the sections below.

This research paper contributes a framework for understanding the potential of urban ponds to meet water supply needs in South Asian cities and city regions. This is an area where little systematic research has been done to date. The research will eventually contribute to our understanding of the potential for urban ponds to be networked into urban and regional water supply systems and the governance of such a system. It will also identify knowledge gaps where research efforts need to be prioritised to fully integrate local urban ponds into resilient water-supply provision and making them an integral part of the urban waterscape.

Can Ponds Tackle Water Scarcity and Build Resilience?

South Asian Cities are facing Acute Water Shortages

Before going into the specifics of ponds and currently used water systems, the wider situation concerning freshwater availability for urban use needs to be appreciated. In the cities of South Asia, the stress on water resources is increasing at an alarming level. This is driven by rapid population growth, competition for limited water resources from industry or agriculture, and unsustainable exploitation or contamination of groundwater resources. In the context of more intense precipitation and flooding seen widely across South Asia (for example during the 2019 Monsoons), such paucity of water within urban areas is even more noticeable. Water stress is now chronic in many cities and is expected to intensify with climate change. It is expected that 5.7 million people will face water stress for at least one month each year by 2050 according to Mitlin et al. (2019). Factoring in both climate change and urbanisation, more than 27% of 482 cities around the world will have unmet water demands by 2050 and an additional 19% of cities relying on surface-water transfer from other regions will likely experience water conflicts between urban and agricultural needs (Flörke et. al. 2013).

South Asian cities are particularly at risk of water stress. In India alone, 160 million persons are living in cities that are water stressed (Padmanabhan and Srivastava, 2019). A study by McDonald et al (2014) on the most water stressed large cities globally, identified 24 Indian cities that are in this situation already. This includes all the metropolitan cities and smaller yet significant cities such as Ahmedabad, Jaipur and Bhopal, the latter ironically known widely in India as the ‘city of lakes’.

The most recent and striking illustration of catastrophic water shock in a South Asian city was evident during the 2019 drought in Chennai city (capital of Tamil Nadu state and one of India’s biggest metropolitan areas), where the media widely reported a *‘train carrying millions of litres of water rolled into the southern Indian city of Chennai, providing desperately needed relief to residents who have been facing an acute water shortage for over a month’* (Gupta, 2019). This situation of water running out was dubbed widely by the media as *Day Zero*. The 50-wagon train locomotive wheeled in 2.5 million litres of water in one visit from a reservoir 360 km away in a location called Jollarpettai. The train was therefore expected to supply 10 million litres of water each day to the city. For reference to appreciate the full scale of the water deficit and stress, the Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) estimates actual daily demand for water in Chennai as 1,200 million litres per day. This is 120 times what the emergency train could supply each day.

Many cities of South Asia are turning towards groundwater resources for urban and regional water supply and formal or informal withdrawal of groundwater is a widespread way to meet water demands. Such is the scale of exploitation that in 2018, the government of India’s *Niti Ayog* (planning commission) reported that by 2020, 21 major cities, including Delhi, Bangalore and Hyderabad, are expected to reach *zero groundwater levels [sic]*, indicating that the level of groundwater is dropping rapidly and will not be possible to be extracted, affecting access to water for 100 million people in these urban areas.

A strong link exists between ground water resources and regional and local climatic patterns. The majority of groundwater replenishment in South Asia comes from annual precipitation during the Monsoon season. It has been estimated by the Central Ground Water Board in India (CGWB,

2018) that at its peak during the Monsoon period in South Asia, the Monsoon rains contribute 70% of the recharge of ground water. In drier seasons this is less than 60%. Recharge dependency of groundwater in Bangladesh is even higher, up to 80% from seasonal Monsoon precipitation. Therefore, any changes in the timing, duration and intensity of Monsoon precipitation combined with rate of surface run-off can significantly influence the recharge of groundwater.

Amongst the 6,584 ground water assessment units (Blocks/Taluks/Mandals/ Districts/Firkas/Valleys) in India, 1,034 were categorized by the Indian CGWB (2018) as over-exploited in the use of groundwater, 253 as critical, 681 as semi-critical, and the remaining units as safe. There were 96 assessment units (mainly along the coastline) that were completely saline. The number of over-exploited and critical administrative units is significantly higher in Delhi, Haryana, Himachal Pradesh, Karnataka, Punjab, Rajasthan and Tamil Nadu, Uttar Pradesh, where agriculture and cities and towns with large populations and industry dominate water consumption as well as compete for water resources with agriculture.

As cities in South Asia grow, the demand for domestic water will increase and the competition with agriculture and industrial water demand will intensify.[2] Whilst the overall predominant user of water resources is agriculture, industrial and domestic water consumption are the predominant issues for urban regions.

Considering the scale of the freshwater shortage, surprisingly few large cities (defined as cities with a population in excess of 750,000) have comprehensively assessed their water resources according to McDonald et al. (2014), making it difficult to address the issue at its root causes; instead these cities are relying on large-scale water transfer. *"The urban water infrastructure of large cities cumulatively supplies 668 billion liters daily. Of this, 504 billion liters daily comes from surface sources, and that water is conveyed over a total distance of 27,000 ± 3800 km. Land use in upstream contributing areas affects the raw water quality and quantity of surface water sources. While large cities only occupy 1% of the Earth's land surface, their source watersheds cover 41% of that surface, so the raw water quality of large cities depends on the land-use in this much larger area",* according to McDonald (2014, p. 100). The strategic assessment of water resources and the management of these cities' water sources has high significance to the global urban economy, food production and other critical land uses. The findings in this study highlight that four of the most populous cities with cross-basin transfers are in South Asia namely Mumbai, Karachi, Ahmedabad and Chennai. These cities also have the largest cross-basin transfers in the large cities category for the samples taken for the study with cross-basin transfers, defined in this study as the surface withdrawal of water from a drainage basin that is not part of the urban agglomeration.

With more water withdrawn from various sources for consumption, the amount of wastewater released in urban areas has also increased, with the share of untreated wastewater rising significantly. The Central Pollution Control Board of India highlighted that this not only poses a direct public health hazard but also threatens the contamination of already fast depleting groundwater sources. The two main reasons responsible for deterioration of water resources according to Kumar et. al. (2014) are the disposal of untreated or partially treated effluents into rivers and lakes, and runoff from urban and agricultural areas. In Indian cities there is a 'gap of 26,468 million litres/day in sewage treatment capacity' according to Kaur et al. (2012). This leads to extensive pollution of natural rivers and ground water. In addition, the quality of 'treated'

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[2] Growth in demand for use in domestic and industrial purposes is in line with global trends. Florke (2013) notes that global domestic water use has continuously increased since 1950, driven by the growing population and rising prosperity.

effluent from sewage plants may not comply with environmental standards, which must be kept in mind as an additional hazard to the quality of surface water and groundwater sources.

As water deficits increase in South Asian cities, even for households that are connected to 'improved' piped networks, urban dwellers now rely increasingly on tube wells and boreholes for water supply, even more than utility-based supply networks. There is a rapid growth in in-situ extraction of groundwater, either formally or informally, to keep up with demand. It is worth recalling that groundwater sourced supply is itself intricately linked to climate, with recharge depending heavily on seasonal rainfall.

Increasing contamination of groundwater in South Asia may make it less and less desirable to extract groundwater for domestic consumption. Untreated sewage can also be considered, a commonly occurring contaminant. More than half of South Asia's groundwater is believed to be too contaminated to use (The Guardian, 2016), particularly across the Indo-Gangetic plain mainly through contamination by naturally occurring arsenic and salinity (particularly in coastal cities). The presence of fluoride, ammonia, hardness, pesticides, faecal matter in groundwater, tap water as well as bottled water has also been reported. Hirji et al. (2017) point out that the occurrence of both microbiological as well as mineral contaminants is common in groundwater.

A combination of growing demand for urban water competing with agriculture, climate change, weak infrastructure, poor understanding of surface water assets, over-exploitation of groundwater resources and contamination of water reserves results in increasing severity of water stress in the cities of India and other countries in South Asia. Therefore, cost-effective measures to meet water demand for rapidly expanding urban areas is a significant challenge but one that must be addressed in priority for urban and regional planning in the coming decades.

Limitations in Current Water Infrastructure for Meeting Freshwater Demand

For numerous major cities in India, Bangladesh and Nepal the 'formal' water supply comes almost completely from distant sources at more than 100 km away from the city (Mitlin et al., 2019). As most South Asian cities do not manage to provide round-the-clock and reliable water supply to city functions, informal groundwater extraction within the city is rampant.

Inter-basin water transfers and dams continue to be presented as solutions to meet the increasing water demands from agriculture and urban areas in many regions of the world (Domenech et al., 2013). However, due to their impact on the ecology, displacement of indigenous population who depend on watersheds for their livelihood and the high capital and operating costs involved, such projects are often socially contested. In India, the large dams and reservoirs in Tehri and Narmada are well known examples where decades of public protests have taken place against large dams to protect catchments vital to the life and livelihoods of communities.

In the South Asian context, the financial gap between the capital and operational costs of delivering large water supply projects and the low paying capacity or sometimes even low willingness of end users to pay makes the business case for large projects very challenging. In order to gain the efficiencies from large-scale piped water supply, the maximum possible percentage of end users need to be paying subscribers to a utility. Mitlin et al. (2019, p. 3) argue that where '*natural sources of water, such as rain, ground or surface are available, some households obtain some water less expensively or for free*'. Aside from free natural sources, the next most cost-effective source is water piped to a dwelling or yard and '*cities and water utilities should work together to extend the formal piped network, address intermittent water service, and* *make water more affordable*'. However, in many South Asian cities, this is currently not the case; there are severe backlogs in the provision of piped networks and limited subscriber connections. A lack of a 24-hour or reliable water supply in the piped network requires subscribers to rely on a variety of sources for water. Such users also tend to use more water at higher cost. McKenzie (2009) reasons that '*consumers store water, which they then throw away to replace with fresh supplies each day'*. A survey of Delhi by Ze'rah (2000) identified that households paid up to 5.5 times for unreliable water, which they would have paid their municipality for as piped supply. Householders with piped water supply also had to make additional investments such as water tanks, hand-pumps and tube-wells. The survey also found that the installation of booster pumps on the main water supply increases the risk of contamination of the general water supply and reduces the pressure in the network for other users, leading them to also install motors on the main line.

Adequate maintenance of the piped water network is also a significant issue and cost in South Asia. The 2016-17 Economic Survey of Delhi (ESD) estimated losses of around 40% of its drinking water supply during distribution caused by poor infrastructure (leaking pipes) and water theft. Theft and non-payment of power also create a barrier for utilities in India to deliver cost-effective and reliable water supply.

At the same time, there is insufficient testing to confirm that 'improved' water supply to replace contaminated sources has reduced public health hazards. Luby (2008) points out that in the 1970s shallow tube wells were heavily popularised to replace the use of contaminated surface water, however, this in itself has not reduced incidents of diarrhoea in the families that used tube wells. Therefore, the actual health impact of designed 'improved' public health interventions may itself need to be better studied.

Water Systems in Reference Cities

At considerable capital cost (7% of 2001 GDP), has Nepal set up a long distance piped water project to bring water to Kathmandu. This was criticised as uneconomic and unaffordable, raising calls for the use of local Kathmandu water before water was brought into the city over long distances from Melamchi (Domenech et al., 2013), highlighting underused water resources within Kathmandu Valley, including rainwater and traditional stone spouts (fed by mountain springs) that could be better managed and utilised. Kathmandu Valley, with an average rainfall of 1,100 mm per year and a catchment area of 600 km^2 could generate about 330 million cubic meters of water per year. Part of this will be sufficient to meet the annual domestic water requirements of Kathmandu, highlighting the potential for rain-fed water supply systems to meet domestic water requirements in Kathmandu.

The Khulna Water Supply and Sewerage Authority (WASA) in Bangladesh, similarly, has proposed the transmission of ground water from 100+ wells up to 47 km away from Khulna City Corporation (KCC) area at a projected capital cost of 365 million USD. In 2011, at the time that the above project was designed, less than 18% of the 1 million city dwellers had a piped water supply and relied on local water from the river, ponds and shallow tube wells. Observations and discussion with local specialists showed that the feasibility stage of the project (due for completion in 2025) was designed to meet 50-60% (110,000 m^3 day^{-1}) of the projected water demand of 230,000 m^3 day^{-1}. Contrast this with the 266,500 $m^3$of water (authors' estimate) that falls as rain within the surface area of 50 km^2 occupied by the Khulna city corporation itself. After rain falls to the ground in Khulna, it fills up the 3,000+ ponds in the city, the rest runs off into drains, mixing with pollutants such as untreated sewage. This contaminated water then needs to be pumped out into the tidal river flowing past Khulna at significant cost (using fossil fuel energy). Khulna's annual expenditure for pumping surface run-off out of Khulna is in the tens of thousands USD, resources that could perhaps be better spent on the capture of surface water run-off and preventing its contamination. The rationale for transporting large quantities of water therefore does not fully explore the potential of local precipitation capture. Notably the feasibility document for the project does not take into account the 3,000 plus local ponds that are present in the KCC area. The reason often coming up in discussion is that many of them are under private ownership and therefore not accessible to the local authorities for inspection or use.

The drying up of large reservoirs where Chennai draws down the water to meet its daily water demand of 1,200,000 m^3 day^{-1} is largely attributed as the cause of the 2019 Day Zero. After the current crisis, work has started already in Chennai to install additional plants to increase desalination capacity (from 200,000 m^3 day^{-1}) to 750,000 m^3 day^{-1} at a cost of approximately 745 million USD (The Hindu, 2019b). Other concerns have been raised about desalinated water, such as its impact on local fisheries (owing to deposition of brine), poor quality of potable water, intensive use of electricity and financial sustainability. In India, electricity and water tariffs are set by the state government and considering the large number of low-income households, water rates are kept much lower than what the business model for desalination plants will expect to recover from water subscribers. Within this context, the 1,000 mm annual average rainfall in Chennai offers significant potential for rainwater capture locally to reduce (if not entirely remove) dependence on energy intensive and environmentally questionable salination methods.

Turning to Local Precipitation in the Context of Contaminated and Depleting Groundwater

Using local water sources instead of transporting water over long distances will reduce environmental impact and support the conservation of donor basins according to Domenech (2013), in the process also avoiding any potential conflicts with communities who rely on those basins for their livelihoods.

Direct capture of rainfall into protected urban waterscape features can be investigated as an option to avoid contamination with pollutants such as pesticides, plastics and faecal matter. Looking around South Asian cities such as Chennai, Khulna and Kathmandu there are several examples of such infrastructure historically built. In his seminal book *Aaj bhi kharain hain talaab* (The ponds are still good) Mishra (2011) highlights the long-standing tradition of building hundreds of thousands of local structures all across Indian towns and cities to capture local precipitation. Numerous social rules and behavioural codes also developed amongst communities in Indian towns and cities to prevent the contamination of local precipitation captured in local water bodies. How community skills, capacity and behaviours around such waterbodies diminished with the advent of 'municipal management' and 'improved supply' requires further study.

Rainwater harvesting (RWH) can be an effective source of non-potable domestic water, although evidence on the feasibility and economic benefit of RWH appears to be thin, despite legislation now widely supporting this solution (Sakib, 2019). For sure, harvesting water where it falls as rain can save money, fuel and energy for transporting or extracting water from the ground. Preeti et al. (2019) also highlight (based on RWH across different climatic zones in Australia) that RWH can be viable across all locations that are dry and reliant on groundwater resources, for example in Australia, and proposed 11 different tank and reservoir designs for different climate zones of Australia.

The following table summarises the observations in three cities of South Asia (Khulna, Chennai and Kathmandu) against the research questions, linking the potential of rainwater capture, urban ponds and the current water supply system in place.

Table 1. Tale of three cities.

	Chennai, India	**Khulna, Bangladesh**	**Kathmandu, Nepal**
What is the acknowledged scale of water shortages in the city?	The daily freshwater demand for domestic water is estimated at 1,200,000 m^3/day^{-1}. As recently as 2019, the city experienced a Day Zero, where the city was unable to supply any water.	The daily freshwater demand for domestic water is estimated at 230,000 $m^3 day^{-1}$. The actual supply is less than a quarter of the demand with groundwater salinity exacerbating freshwater availability.	The daily freshwater demand for domestic water is estimated at 1,110,000 m^3/day^{-1}. The actual supplied water is estimated at a third of this.
Cumulative annual precipitation on surface area.	1,630,130 m^3/day^{-1} (based on average annual rainfall of 1,400 mm on 450 km^2)	266,500 m^3 day^{-1} (based on average annual precipitation of 1,946 mm on 50 km^2)	1,808,220 m^3 day^{-1} (based on average annual precipitation of 1,100 mm on 600 km^2)
What are some of the climatological, environmental and social limitations of the ways in which the city and city regions are currently obtaining water?	The city supply relies upon water transfers from reservoirs in the city region and desalinated water. These processes are financially and energy intensive and unaffordable for poorer households. Environmentally they impact local fisheries for instance (owing to deposition of brine).	The city supply is heavily reliant on groundwater extraction in the city region and water transfer over long distances and therefore financially and energy intensive. The unsafe disposal of sewage contaminates rainwater run-off. Groundwater sources are highly prone to salinity and pollution. A fraction of the city residents has access to piped water connections.	The city water provision relies on long distance water transfer making the process financially and energy intensive. A fraction of the city residents has access to piped water connections.
Is there sufficient provision within existing policies and systems to harvest rainwater for domestic water provision?	Current policies make rainwater harvesting mandatory. Within the current water provision system rainwater harvesting systems suffer from poor coverage, design and maintenance.	Current policies promote rainwater harvesting. The current water provision system in Khulna is predominantly groundwater-fed, with some large ponds in use though not integrated with the domestic water provision network. Building level rainwater harvesting suffers from poor coverage, design and maintenance.	The latest policy, dated July 2019, promotes ‘alternative’ provision methods such as rainwater harvesting at household and communal level. Within the current water provision system rainwater harvesting systems have poor coverage, design and maintenance.
What are the current use and conditions of urban ponds and wetlands?	There are hundreds of ponds, traditional tanks and some large reservoirs within the city region. The linkage of these water bodies with city water provision networks is poor. Several water bodies (particularly tanks) are in private	There are more than 3,000 ponds within the city region. The linkage of these water bodies with city water provision networks is poor. Several water bodies are in private ownership. No systematic open data on the condition or capacity of	There are hundreds of *dhunge dharas* (streams) connected with stone water spouts within the city region. The linkage of these water bodies with city water provision networks is poor. No systematic open data on the condition or capacity of

	Chennai, India	**Khulna, Bangladesh**	**Kathmandu, Nepal**
	ownership. No systematic open data on the condition or capacity of these water bodies. Some of these waterbodies (particularly tanks associated with temple sites) are visibly in use by communities.	these water bodies. These waterbodies are extensively used by communities.	these water bodies. These streams are visibly used by communities to obtain water for a variety of domestic purposes.
Is there potential for using urban ponds to reduce domestic water stress whilst minimising the adverse environmental impacts of current water provision choices?	There is underused capacity to capture and store rainfall within the city limits with due consideration given to public health measures and some repair works will be required to the ponds and tanks. Where applicable pond owners, local communities and small businesses can be engaged to manage and maintain these. It will also reduce the demand for financially and energy intensive transfer of water over long distances.	There is underused capacity to capture and store rainfall within the city limits with due consideration given to public health measures and some repair works will be required to the ponds and tanks. Several ponds are already in use by communities but not linked to the water supply system. Where applicable, pond owners, local communities and small businesses can be engaged to manage and maintain these. It will also reduce the demand for financially and energy intensive transfer of water over long distances.	The *dhunge dhara* streams, and the structures that enclose them are commonly used by communities who are not linked to the water supply systems. Local communities and small businesses can be engaged to manage and maintain these. It will also reduce the demand for financially and energy intensive transfer of water over long distances.
What further research and data related to technical and governance issues can be promoted to enable the integration of ponds within water provision systems?	Condition, capacity and ownership of waterbodies. Willingness and capacity of urban authorities, owners and communities to participate in the management of these water bodies for urban water provision. Public health measures that will ensure ponds are carefully restored and do not increase risk of vector borne disease. Engineering measures to link the ponds with local water provision.	Condition, capacity and ownership of waterbodies. Willingness and capacity of urban authorities, owners and communities to participate in the management of these water bodies for urban water provision. Public health measures that will ensure ponds are carefully restored and do not increase risk of vector borne disease. Engineering measures to link the ponds with local water provision.	Condition, capacity and ownership of waterbodies. Willingness and capacity of urban authorities, owners and communities to participate in the management of these water bodies for urban water provision. Public health measures that will ensure the streams and ponds are carefully restored and do not increase risk of vector borne disease. Engineering measures to link the streams and ponds with local water provision.

Resilience Potential and Scale of Surface Water Ponds

Globally, the surface area under ponds and small lakes appears to be underestimated and poorly studied, according to Downing (2009). Urban ponds are waterbodies of up to 5 ha and in sheer numbers can be vital for the management of ecology and biodiversity at the urban as well as the regional scale (Hassall, 2014), particularly towards vital micro-biota as well as amphibians. Wetlands (including small ponds), according to Imran (2019), are also valuable natural resources for groundwater recharge, flood control and water quality improvement therefore contributing significantly to resilience. In South Asian conditions, where a normal Monsoon has good reach, it is estimated that rainwater harvesting can provide a million litres of surface water per annum for each hectare of land. It is also possible to provide arsenic-free water, particularly close to water collection with nano filtration.

In their study of urban freshwater biodiversity refuges, Chester and Robson (2013) describe ponds as one of 16 types of man-made freshwater stores, garden ponds, industrial ponds, ornamental lakes, drainage systems and nature reserves. While some habitats (such as stormwater management facilities) are very well studied, ponds dedicated to the preservation of nature or water supply in urban areas are poorly understood (Hassall, 2014).

Advances in GIS, satellite imagery and computer-based modelling of seasonal water demand and supply, will open up new opportunities recognising the potential of urban water bodies. Ambitious use of urban water bodies has been proposed by Tsaia et al. (2019) as part of IWRS (*intelligent water reallocation systems*) for drought under urbanisation using ponds. Under such plans urban water bodies (such as irrigation canals or ponds) hold water that can be efficiently channelled to the most critical user based on computer modelling of competing demands from urban, agriculture and industrial sectors in various seasons. However, the starting point of all such ambitious projects is to understand the location and condition of urban water bodies.

Extent of Available Ponds in the Reference Cities and Beyond

The Department for Public Health Engineering (DPHE) in Bangladesh estimates that there are 1,288,222 ponds in Bangladesh alone but about 17% of these dry up in warm weather. In the case Khulna, over 3,000 ponds and small tanks are known to exist within its designated KCC jurisdiction of 50 km^2. As many of the water bodies lay within private boundaries, their condition cannot be readily verified. In Bangladesh, environmental laws prohibit water bodies such as ponds from being filled up without due permissions, however, a local specialist estimates that as many as half of these could potentially be modified or filled-up to build over. Efforts are being made across Bangladesh to confirm the extent and value of urban wetlands and ponds. For instance, 81% of Dhaka city was suitable for natural recharge in 2018 (Islam, 2019) and the protection of these zones is key. In coastal areas of Bangladesh, where salinity already contaminates groundwater, protected ponds (with pond sand filters) are being popularised in government policy and recent programmes (Alam, 2019).

Following the crippling drought of 2019, the city corporation of Chennai is also now starting to look more seriously at the smaller water bodies (Bhardwaj, 2019). The city corporation will not be starting from scratch; historically, town planning In India coincided with the building of ponds and tanks to enable local water storage rather than bring water over long distances (Mishra, 2011). Furthermore, Pandey et al. (2003) highlight that large scale building and maintenance of tanks and ponds coincided with monsoon failure over 8,000 years of practice in evidence. As part of this legacy, the urban region where Chennai is now located has 53,000 ponds and tanks, almost 1,000 of which are located inside the current boundaries of Chennai City Corporation (CCC). Recent droughts across the country have led to other policies and programmes to recognise the significance of restoration of historic wetlands and ponds, though this was not always effective. Panigrahy et al. (2012) at ISRO (Indian Space Research Organisation) mapping of wetlands in India notes that tanks/ponds smaller than 2.25 ha also form important wetlands and estimate 555,557 of such small wetlands in the country.

Rainwater harvesting has been mandatory for several years in cities such as Chennai, though it has been hindered by encroachments, unplanned urbanisation and indiscriminate pumping of water in the city. Even though "*most buildings in the city have rainwater harvesting structures, after it was made mandatory in 2003, many of them are either not maintained or are inadequately designed"* (The Hindu, 2019).

Similarly, despite the plethora of policies and acts for the protection and restoration of urban lakes and wetlands, urban water bodies of India are in extremely poor condition and their numbers continue to diminish rapidly. The Centre for Science and Environment (2012) adds examples that at the beginning of 1960s Bangalore had 262 lakes, of which only 10 held water in 2012. Similarly, in 2001, according to Excreta Matters (2012), 137 lakes were listed in Ahmedabad city, but over 65 were built over. In Delhi in 2010-11 changes in water bodies in the previous 10 years found that 21 out 44 lakes were dry due to rapid urbanization and falling water tables (Singh and Bhatnagar, 2012). Since 2000, Hyderabad has lost 3245 ha of its water holding lakes and ponds (The Hindu, 2012).

In Kathmandu, the traditional urban water supply systems of *dhunge dharas* (spring water) are still used across much of the city, providing domestic water facilities whilst the municipal piped supply is still in the process of being rolled out. Andrews and Weitz (2002) describe the use of these spouts as an essential source of water for middle- and low-income residents across the city of Kathmandu. In a water scarce city these spouts provide equitable access to a public water supply. Depending on their location in the city people, may spend up to 45 minutes to access the nearest *dhunge dharas*, even waiting in a queue for 6 or more hours. Water from these spouts is free, but the community looking after them may charge a small fee for their maintenance and improvement. The lack of effective institutions and resources to undertake this management threatens the sustainability of this traditional water supply spouts' sustainability.

Governance and Partnerships in South Asia for the Development of Urban Ponds as Water Sources

The governance of water systems is an important component of city resilience strategies (Tyler and Moench 2012). Therefore, it is important to appreciate how the ponds are currently perceived within municipal methods of water provision and the potential governance arrangements for a system that links ponds into urban water provision.

An almost instant reaction from local authorities in discussions about urban water bodies is to highlight the risk they present of vector borne disease such as malaria and dengue, as the vectors procreate in standing open water. Boelee (2013) points out that transmission of disease will depend on inter-linkages between several factors, such as local climate, agro-ecosystem, human health behaviour. Therefore, it is over-simplistic to argue that the presence of an open water body alone results in vector borne disease, though it is something that certainly requires further investigation in the South Asian context. A further caveat is added: *"currently, too little thought is given to the possible public health implications of different options for rainwater harvesting and water storage...care must be taken not to increase the health burden of already vulnerable people"*. This makes the appropriate design and management of open water bodies important. Including adequate public health measures and the healthy upkeep of a water body also requires the support of communities living close to it. As pointed out earlier, citing Mishra (2011), in traditional urban planning in South Asia, water bodies were essentially managed by communities who have learnt the necessary skills and behaviours over decades and centuries of practice. Such close engagement and skills base have diminished with the advent of municipal management of water bodies.

There is a plethora of other reasons that ponds diminish or face constraints as a serious source of water. Simplistic definitions of urban ‘ponds’ or ‘lakes’ leave them vulnerable to exploitation, for instance, if the definition is based on depth of water, seasonal changes in water levels it may have been ignored. Therefore, instead of providing a distinct identity or protection to a waterbody, this limited criterion works in favour of commercial elements in the community for whom the only significance of a waterbody is its land value. CSE (2012): absence of a specific land use category for urban water bodies; absence of systematic coordination between institutions and civil society protecting water bodies; absence of reliable data on the location, ownership and condition of water bodies as we have seen in the example of Khulna; lack of an ecosystem approach due to which the watersheds, catchments and shoreline are not adequately protected; lack of participation, skills and capacity building amongst the community adjacent to the waterbody. As mentioned above, since modern-day municipal governments took over the management of urban water bodies, centuries-old traditions and skills within local communities for managing water bodies and their catchments have been marginalised and diminished.

Urban ponds are also not yet in the list of recognised water sources for ‘improved’ water supply, as the table below from the World Health Organisation (WHO) shows. Hassall (2014) states that in other parts of the world, ponds have also been overlooked from a legislative standpoint. For instance, they are omitted from the EU Water Framework Directive (2000/60/EC) that determines standards for water quality in European Union member states. Although on a positive note, EU funded projects in South Asian context such as *saph pani* (clean water) are implementing surface water based water supply projects.

Table 2. Improved drinking water sources according to WHO.

- Piped water into dwelling, plot or yard
- Public tap/standpipe
- Tube well/borehole
- Protected dug well
- Protected spring
- Rainwater collection

Source: World Health Organisation (2006)

A change in attitude and systems is also needed in how we conceptualise, resource and govern our water supply for fast growing cities with rapidly depleting resources. Indumathi Nambi[3] has proposed a decentralised system that stores and supplies water with each reservoir having a treatment plant. The Hindu (2019) has further reported that in a single apartment block in Chennai “[*Federation of OMR Residents Association in Chennai] residents were able to harness 10 lakh litres (0.1 million litres) of rainwater even during the drought in 2019... During a good monsoon, three times more can be collected.*”

In Bangladesh, the Department of Public Health Engineering (DPHE) has started a project on ponds/*dighi*/ditches owned by Zila Parishad (district authorities), covering 42 districts in which 809 ponds will be re-excavated and equipped with localised filters, allowing addressing quality

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of surface water and reducing reliance on groundwater (Alam, 2019). Again, the training and behavioural change amongst the local community to take ownership is considered vital for the success of this programme. At a workshop with the community in Khulna in December 2018, community groups expressed interest in learning about examples from India on how communities can be legally empowered to engage with and look after urban water bodies.

The Indian Ministry of Environment and Forests (MoEF) has asked all states to constitute City Level Monitoring Committees (CLMCs) for all river and lake conservation projects and to aid coordination between the Centre, states and urban local bodies (CSE, 2012). MoEF shares 70% of the involved cost of the restoration projects under NLCP. Where the quality of urban lakes has deteriorated, Public Interest Litigation (PIL) has been an instrument used extensively by citizens to draw attention to the issue.

Awareness and enthusiasm created by recent RWH laws and environmental activism in India has also catalysed initiatives for the revival of water bodies and temple tanks. As an illustration of the state of Rajasthan's MukhyaMantri Jal Swavlambhan Abhiyan (MJSA) focuses on restoration of small waterbodies and strengthening community engagement with their management and maintenance. India's *Niti Ayog* (2018) has reported that the state has leveraged technology such as drones to map traditional water bodies for restoration. Participation of the community in reviving, maintaining and monitoring water bodies has been encouraged, also donating funds to the campaign and undertaking conservation efforts. As recently as 2020, the Punjab and Haryana High Court in India declared Sukhna lake (Chandigarh) a *living entity*, giving it rights against harm akin to a living person.

Experience from India on management of assets by communities (Theis and Kalra, 2005) shows that where community members and householders have explicit responsibility for maintenance, it can be done cost-effectively and it also helps to develop associated benefits such as skills and livelihoods within the community.

There is also evidence across South Asia of similar functioning small community networks for water supply, formally referred to as *Small Scale Private Water Providers* SSPWP(s). In South Asia SSPWPs currently provide 5-15% of the water supply alongside utilities, according to Asian Development Bank. Andrews and Weitz (2002) highlight that small network operators care about their water quality. While they may not have treatment facilities, they advise their customers on the potability of their water, ensure reliability and often invest for the long-term benefit of their business and customers.

Concluding Remarks and Recommendations for Further Research

The paper set out to clarify the potential of urban ponds linked into the water system(s) of South Asian cities and enhance their resilience. The research was framed by questions about the extent of water stress in large South Asian cities, the limitations of their current freshwater provision systems for urban areas and how well these are linked with rainwater capture inside urban areas. The research then explored the potential for urban ponds to enhance resilience and alleviate freshwater scarcity in South Asian cities. With reference to three cases, Khulna, Chennai and Kathmandu, the paper set out to observe the potential for capture of rain in these locations, current governance conditions and the role of ponds in their water supply as well as the resilience benefits and co-benefits of linking ponds into the water system.

The main findings from the cases are:

1. Much of South Asia’s urban water supply competes with agricultural demand and depends heavily on annually variable precipitation to recharge groundwater reserves. The latter are increasingly contaminated and overexploited and therefore not a sustainable source of freshwater water in the coming decades. South Asian city regions are therefore expected to be some of the most water stressed urban locations anywhere in the world.
2. The current water provision in several major cities in South Asia relies heavily on water transfer across the city region. This method is energy and financially intensive. In the South Asian context, the business viability of such systems, affordability by the low-income population, impacts on the livelihoods of water basin communities and the environmental footprint are major concerns for sustainability and ecosystem resilience.
3. Across the region there is widespread support through policies and regulations to capture rainwater at the household and communal level. In some cities this is even mandatory, whilst in others it is recommended or proposed. However, mainstream city water systems do not factor in or integrate rainwater capture and ponds. From visual observation, the coverage, design and maintenance of these systems can be considered poor.
4. Historically, many South Asian cities built community-managed ponds and tanks for water provision. However, they have declined with the advent of municipal management of water provision; it requires further research to find out why. In many cities of South Asia for instance Khulna, Kathmandu and Chennai, such structures are visible and informally continue to serve communities where they have not fallen into disrepair. In the context of rapid urbanisation such natural or human-made water provision assets are vulnerable and are being lost at a rapid rate.
5. Ponds offer significant potential for water provision if local precipitation can be captured and kept free from contaminants, with co-benefits for resilience, ecological diversity and minimising the environmental footprint. This is evident in both the literature as well as in projects being carried out (such as country-wide ponds restoration in Bangladesh and India). However, like any other ‘improved’ water supply, the dimensions of regulation, finance, municipal governance and public health impact will require further study to create a strong technical and business case.

Overall, in response to the research questions, large South Asian cities like the ones reported on here, are facing severe water scarcity. Groundwater extraction (formal and informal) and water transfer over long distances are primary sources of freshwater for many cities, though these methods have several limitations owing to overexploitation, contamination, intensive costs, high energy consumption and limited network coverage for users, particularly the poor. There is policy support within all three reference cities for capture of rain falling in urban areas at both the household and the communal level, but the hundreds of existing ponds and surface reservoirs are in poor condition and not linked to mainstream the municipal water provision system. Where communities have access, they informally rely on these for their day to day freshwater needs. Capturing the significant amounts of rain falling on urban areas into ponds and linking them to water systems has clear benefits to reinforce the existing water supply system with additional resilience benefits such as biodiversity enhancement, community empowerment, skills and income opportunities. This is, however, time sensitive as many ponds and surface reservoirs are disappearing due to rapid urbanisation.

Rainwater capture into local ponds, their connectivity to the urban water system and its governance in partnership with users work well with the theoretical model of a resilient water system that proposes interlinked and decentralised resilience components and user engagement.

The example cities and their water supply schemes do not have convergence with this model. Several of such surface water bodies in these cities are disappearing fast and in the context of contaminated and depleting ground water, the reliability and resilience in the water systems is quickly compromised as was evident in Chennai, which experienced Day Zero in 2019.

After the shock of 2019, Chennai is investing further in desalination but also shows a renewed interest in linking its water supply to significant surface water storage capacity within the urban region. For Chennai, and other cities in South Asia or elsewhere, wanting to build upon the model of system interlinked and decentralised rain storage in ponds, what will the components of such a model look like? Some of them are set out below and will require further research:

1. Mapping the location, ownership, ecological and physical characteristics of the existing ponds.
2. Willingness and capacity of urban authorities, owners and communities to participate in the management of these water bodies for urban water provision.
3. Public health measures that will ensure the ponds are carefully restored and do not increase the risk to any part of the population (such as with vector borne disease).
4. Management of behaviours and built-form in the catchment of these ponds.
5. Engineering measures to link the ponds with local water provision and ensure acceptable water quality.
6. Legislation and policies that support and incentivise the above.

Systematic studies and data on urban local ponds are patchy and this paper highlighted where research efforts could be prioritised to fully appreciate the suitability of integrating local urban ponds for resilient water-supply provision and making them an integral part of the urban waterscape. The findings from this paper show that there is sufficient evidence to suggest that local urban ponds should be networked into urban and regional water provision systems. It is also clear that urban governance arrangements should be improved, particularly with regard to clarifying:

1. arrangements with regard to the ownership of waterbodies;
2. possible increases in the capacities of urban authorities, owners and communities to participate in the management of these water bodies specifically for urban water provision;
3. options for building a database of financial, public health and resilience outcomes of using urban local ponds for water provision.

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