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Urbanisation and emerging economies: Issues and potential solutions for water and food security

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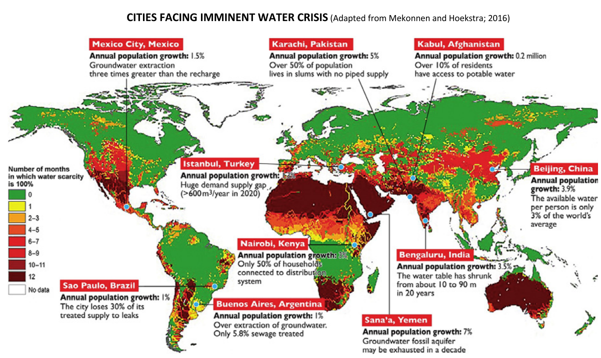
HIGHLIGHTS

- Urbanisation will be one of the 21st century's most transformative trends.
- Worldwide several cities are on the verge of water crisis.
- Over 80% of wastewater is poorly treated and is used to irrigate 11% of all croplands.
- About 60–90% of the urban population in many emerging economies relies on septic tanks.
- We offer several suggestions to mitigate water and food insecurity in emerging economies.

GRAPHICAL ABSTRACT



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ABSTRACT

Urbanisation will be one of the 21st century's most transformative trends. By 2050, it will increase from 55% to 68%, more than doubling the urban population in South Asia and Sub-Saharan Africa. Urbanisation has multifarious (positive as well as negative) impacts on the wellbeing of humans and the environment. The 17 UN Sustainable Development Goals (SDGs) form the blueprint to achieve a sustainable future for all. Clean Water and Sanitation is a specific goal (SDG 6) within the suite of 17 interconnected goals. Here we provide an overview of some of the challenges that urbanisation poses in relation to SDG 6, especially in developing economies. Worldwide, several cities are on the verge of water crisis. Water distribution to informal settlements or slums in megacities (e.g. >50% population in the megacities of India) is essentially non-existent and limits access to adequate safe water supply. Besides due to poor sewer connectivity in the emerging economies, there is a heavy reliance on septic tanks, and other on-site sanitation (OSS) system and by 2030, 4.9 billion people are expected to rely on OSS. About 62–93% of the urban population in Vietnam, Sri Lanka, the Philippines and Indonesia rely on septic tanks, where septage treatment is rare. Globally, over 80% of wastewater is released to the environment without adequate treatment. About 11% of all irrigated croplands is irrigated with such untreated or poorly treated wastewater. In addition to acute and chronic health effects, this also results in significant pollution of often-limited surface and groundwater resources in Sub-Saharan Africa and Asia. Direct and indirect water reuse plays a key role in global water and food security. Here we offer several suggestions to mitigate water and food insecurity in emerging economies.

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1. Introduction

Urbanisation is going to be one of the 21st century's most transformative trends (UN, 2017). Currently, about 4 billion people (55% of the world's population) are living in urban areas. Urban centres will absorb significant rural to urban migration and the bulk of population growth over the next decades. Hence, this proportion is expected to increase to 68%, reaching to 6.3 billion people by 2050, adding 2.3 billion more people to urban areas (UNDESA, 2018). Most of this increase (about 90%) is likely to occur in the two poorest regions of the world, South Asia and Sub-Saharan Africa, where the urban population is likely to double in the next 20 years (UNDESA, 2018).

The fastest growing cities have fewer financial resources than the average city and their annual population growth rate has been found to be negatively correlated with the per capita income (Macdonald et al., 2014). The limited resources cannot keep pace with the need for urban infrastructure development. Besides the fastest growing cities are often located in areas with limited water availability. An analysis by Macdonald et al. (2014) showed that 68% of large cities are in low- to middle-income countries, especially in China, Central Asia and Mexico.

Clean Water and Sanitation is a specific Sustainable Development Goal (SDG 6) within the suite of 17 interconnected SDGs adopted in 2015 by the United Nations, to address water scarcity issues and improving sanitation for all people. SDG 6 covers a range of aspects including drinking water, sanitation and hygiene, treatment and reuse of wastewater and ecosystem health. It is linked to other SDGs, such as Sustainable Cities (SDG 8) and Health (SDG 3). All forms of development (food security, health promotion and poverty reduction) and economic growth in agriculture and industry as well as maintaining healthy ecosystems are linked to water resources (UN SDG-6 Report, 2018).

Urbanisation helps create economic prosperity, as according to the World Bank >80% of global GDP is generated in cities (WB, 2019). However, it has multifarious (positive as well as negative) impacts on the wellbeing of humans and the environment (Table 1). These span from access to and quality of basic commodities, such as water and food, to impacts on human and ecosystem health through wastes (solid and liquid) generated by urban centres and their management (or lack of it). These also include the impacts on people's social, economic and cultural wellbeing. Some specific examples of such impacts and the places where these have already been felt strongly are presented in Table 1. The nature of these impacts varies from region to region depending on the social, cultural and environmental context. Due to its transformative potential, urbanisation and its impacts on communities is high on the agenda of international organisations such as the UN (New Urban Agenda, UN Habitat III) and World Bank Group (WB, 2019).

While a comprehensive coverage of urbanisation and its impacts is beyond the scope of this paper, here we provide an overview of some of the challenges that urbanisation poses to water quantity, water quality, wastewater treatment and reuse as well as sanitation and hygiene. We have done this in the context of low- to middle-income countries, which are facing the dual problems of fast-paced urbanisation and limited financial resources for infrastructure development. Here, we not only highlight the key issues in these sectors for these regions but also suggest a way forward, noting that solutions from the developed world may not be directly transferable from the perspective of socio-economic and environmental conditions of such countries.

2. Key issues

2.1. Water scarcity

The most obvious impact of the centralisation of population in cities or urban areas is on the demand for and access to water, sanitation and rainwater drainage (flood management). The urban water demand is expected to increase by 50–80% by 2050 and this is concentrated in regions where irrigation development is also occurring (WB, 2019). According to a UN estimate (UNESCO, 2016) the number of megacities (with population over 10 million) has grown from 3 in 1970 to 10 in 1990 and 28 in 2014. This number is projected to reach 41 by 2030, many of which will be in the world's least developed economies. Consequently, urban water insecurity is considered as one of the unprecedented challenges facing cities (WB, 2019). Droughts and water shortages in Rome (Italy), Cape Town (South Africa) and Chennai (India) have been widely documented in recent years. Some major cities facing water crisis in recent years have been shown, along with the map of overall global water scarcity, in Fig. 1.

Through an assessment of blue water scarcity, Mekonnen and Hoekstra (2016) noted that two-thirds of the global population (4 billion people) is facing water scarcity at least one month of the year (Fig. 1). Nearly half of these people are in India and China. According to Macdonald et al. (2014), 11 of the largest cities which face water stress are in India (5) and China (6). Indeed, the reservoirs supplying drinking water to the southern Indian city of Chennai ran dry in mid-2019 and drinking water had to be trucked in from regional areas exploiting the regional aquifers, thus shifting the problem. Similarly, other Indian cities such as Bengaluru and Delhi are currently facing serious water scarcity with rapidly depleting groundwater reserves. Worldwide several cities are at the verge of water crisis (Fig. 1).

Urban water insecurity in these cities is clearly due to the interplay of several factors such as population growth rate, the existence of suitable water sources (in terms of their quantity and quality), infrastructure, use and supply efficiency, waste management and overall urban planning, etc. Indeed, meeting the drinking water demand is a huge challenge for megacities. For example, in Mumbai (India) and Lagos (Nigeria), 56% and 66% of the city's populations respectively, live in slums or informal settlements, where the drinking water distribution is essentially non-existent and people draw supplies from other sources (UNESCO, 2016), including private suppliers. Social, political and economic dynamics can drastically change the urban water demand, as shown by several case studies reported by the World Bank (WB, 2019).

2.2. Sanitation & hygiene

As mentioned above, in terms of sewer connectivity, the contrast between the lower- (low and lower-middle) and high-income countries is stark. In high-income nations 90–100% of the population is connected to sewers (e.g. Australia, USA, UK, Japan, South Korea) whereas a much smaller fraction of the population in lower-income countries is connected to sewerage systems. Rapid urbanisation has resulted in division of the urban population between vastly wealthy areas in parts and large impoverished quarters. About 1.5 billion urban people live in informal settlements or slums, e.g. more than half the population in megacities of India (Kolkata, Chennai, Mumbai and Delhi) live in informal settlements (Box 1); Kotter, 2004). A large proportion of the population of the Nigerian city Lagos (which grew 100-fold since 1960) lives in such informal settlements, with the majority not connected to piped water or a sanitation system (Vidal, 2018). Consequently, in the emerging economies, there is a heavy reliance on the use of septic tanks, while in Africa pit latrines dominate aside other on-site sanitation (OSS) systems (Fig. 2.). OSS currently serves >2.7 billion people globally and this number is expected to reach 4.9 billion by 2030 (Cairns-Smith et al., 2014). In the Asian context, the reliance on septic tanks is heavy (Fig. 2). About a decade ago, about 77% of the urban population in Vietnam, 89% in Sri Lanka, 93% in the Philippines and 62% in Indonesia were relying on septic tanks (Willetts et al., 2008; USAID, 2010). Under a recent nation-wide campaign against open defecation by the Government of India (Swachh Bharath Abhiyaan or Clean India Mission) over one hundred million toilets have been constructed in India over the last five years and a vast majority of these are based on septic tanks. In fact, over recent years several countries have changed their sanitation approach to value OSS as a sewer alternative which is better suited to

Table 1
Key impacts of urbanisation on water, food, ecosystem, human health and other aspects, with some prominent examples.

Nature and sphere of impact	Example location (country/cities)	Comments	References
Water			
Extreme scarcity of potable and non-potable water (U/P/F)[a]	Globally, cities of the world facing shortage to a varying degree; ten cities on the verge of water crisis	Urban water demand will increase by 80% by 2050. Four billion people face severe water scarcity for at least 1 month per year and 1.8 billion for at least six months per year; nearly half of those live in India and China. Drinking water reservoir (Mettur) ran dry in Chennai (India) earlier this year and drinking water had to be trucked in. Cape Town (Africa) ran out of drinking water in 2018.	Mekonnen and Hoekstra, 2016; Vanham et al., 2018; Sengupta, 2018; Flörke et al., 2018
Surface and groundwater depletion (U/P/F)	Global overexploitation of surface and groundwaters in urban centres; Bengaluru, Delhi and other Indian cities	11 of the world's 20 largest cities under water stress are in India and China. 61 cities of 481 studied depend solely on groundwater, with 59 experiencing an increasing groundwater footprint. In Bengaluru city of India, for example, the water table depth increased from about 10 m to 90 m in the last 20 years.	Macdonald et al., 2014; Flörke et al., 2018
Contamination of surface water bodies (streams, lakes, rivers etc.) (U/P/F)	Nairobi (Kenya); Accra (Ghana); Bangalore (India) Delhi (India); Sao Paulo (Brazil); Bengal Basin (Bangladesh); Hanoi (Vietnam)	Cross-cutting through most developing countries: large volumes of untreated and poorly treated wastewater discharged into urban and peri-urban streams. Waste from cities contaminating river basins.	Corcoran et al., 2010; McArthur et al., 2012; Drechsel and Keraita, 2014; Jamwal and Lele, 2017; Thebo et al., 2017; Sengupta, 2018
Groundwater contamination from septic tanks/soak pits etc. (U/P)	Puri (India); Bangalore (India); Karachi (Pakistan); Hanoi (Vietnam); Jakarta (Indonesia)	Soak pits and leaking septic tanks have caused significant groundwater contamination in several cities of Asia, Africa and Latin America.	Vijay et al., 2010; Ramesh et al., 2012; McArthur et al., 2012; Sengupta, 2018
Groundwater quality: seawater intrusion (U/P/F)	Bangkok (Thailand); Jakarta (Indonesia); Buenos Aires (Argentina); Istanbul (Turkey)	Over-exploitation of groundwater in coastal cities leading to seawater intrusion. In some cases, the over-exploitation of groundwater is leading to land subsidence, e.g. Mexico City, Jakarta, Beijing.	Onodera et al., 2008; Sengupta, 2018
Food			
Increased availability of locally produced crops (P)	The total area of irrigated croplands within 20 km of urban areas is 130 Mha globally	Direct and indirect wastewater use assures year-round supply of irrigation water to growers in urban and peri-urban areas in the global South, and thus increased productivity.	Jiménez and Asano, 2008; Qadir et al., 2010; Thebo et al., 2014
Aquaculture	Kolkata (India) Kumasi (Ghana) Bangladesh	East Kolkata Wetlands (EKW) are supporting the treatment of the city's wastewater as well as the production of fish, vegetables and rice. The wetlands produce 10,000 t of fish and 40–50% of the green vegetables available on the Kolkata markets. Fish farming in constructed wastewater treatment ponds is also reported e.g. in Ghana where precautionary measures such as fish cooking/grilling prior to consumption is recommended. In Bangladesh, fish production was able to cover all costs of the local wastewater treatment system.	Bunting et al., 2010; Barkham, 2016; Otoo and Drechsel, 2018; Yeboah-Agyepong et al., 2019;
Human and ecosystem health			
Food contamination (U/P/F)	30 Mha globally (China, India, Mexico, Pakistan, and several other countries)	Contamination of food with pathogens and toxicants due to irrigation with domestic and industrial wastewater	Drechsel et al., 2010; Thebo et al. (2014)
Land contamination and degradation (P/F)	Melbourne (Australia): Bangalore (India)	Chemical and microbial contamination of land receiving untreated or poorly treated wastewater and septage with organic chemicals, metals, metalloids. Accumulation of salts resulting is soil degradation (salinization, sodification)	Muyen et al., 2011; Jamwal and Lele (2017)
Ecosystem services and impacts (U/P/F)	Kunshan (China); Kolkata (India); Koh Chang (Thailand); Chennai (India)	Stormwater wetlands in the peri-urban areas can provide a range of ecosystem services. For example, an ecological wetland in Forest Park in the north west of Kunshan city[b] not only improves water quality but supports wildlife by providing habitat for >60 species and 10,000 migratory birds visiting the Park. Contamination of coastal environment from wastewater discharge has been noted in Koh Chang and Chennai, to give two examples.	Barkham, 2016; Nitivattananon and Srinonil, 2019
Livelihood			
Improved livelihood of peri-urban farmers (P)	Accra (Ghana) Cotonou (Benin) Kolkata (India)	Assured year-round supply of irrigation water to growers in the peri-urban areas and thus increased income. Some 30,000 people make a living from the East Kolkata Wetlands.	Van Veenhuizen and Danso, 2007; Barkham, 2016
Increased disease burden and loss of livelihood opportunities (P)		Health impact of wastewater; loss of market due to perception of contamination	Drechsel et al., 2010; Keraita and Drechsel, 2015
Other (social, cultural, etc.)			
Water reallocation from rural to urban (P,F)	North America, Asia, Latin America, Middle East	Transferring water from rural areas to urban centres to meet the demand of urban populations. Estimated to be 16 billion cubic meters of reallocated water per year. Cross-basin water transfers support about 12% of the large cities globally.	Molle and Berkoff, 2006; Macdonald et al., 2014; Garrick et al., 2019
Import of food items and 'virtual water trade' (F)	USA, China, India, Brazil, Argentina, Canada, Australia, Indonesia, France and Germany, Ghana, etc.	These countries are major gross virtual water exporters and together they account for more than half of the global virtual water export (2320 G cubic meter per year)	Hoekstra and Mekonnen, 2012

[a] U/P/F stand for urban, peri-urban and further afield, respectively.
[b] https://watersensitivecities.org.au/solutions/case-studies/forest-park-ecological-wetland/.

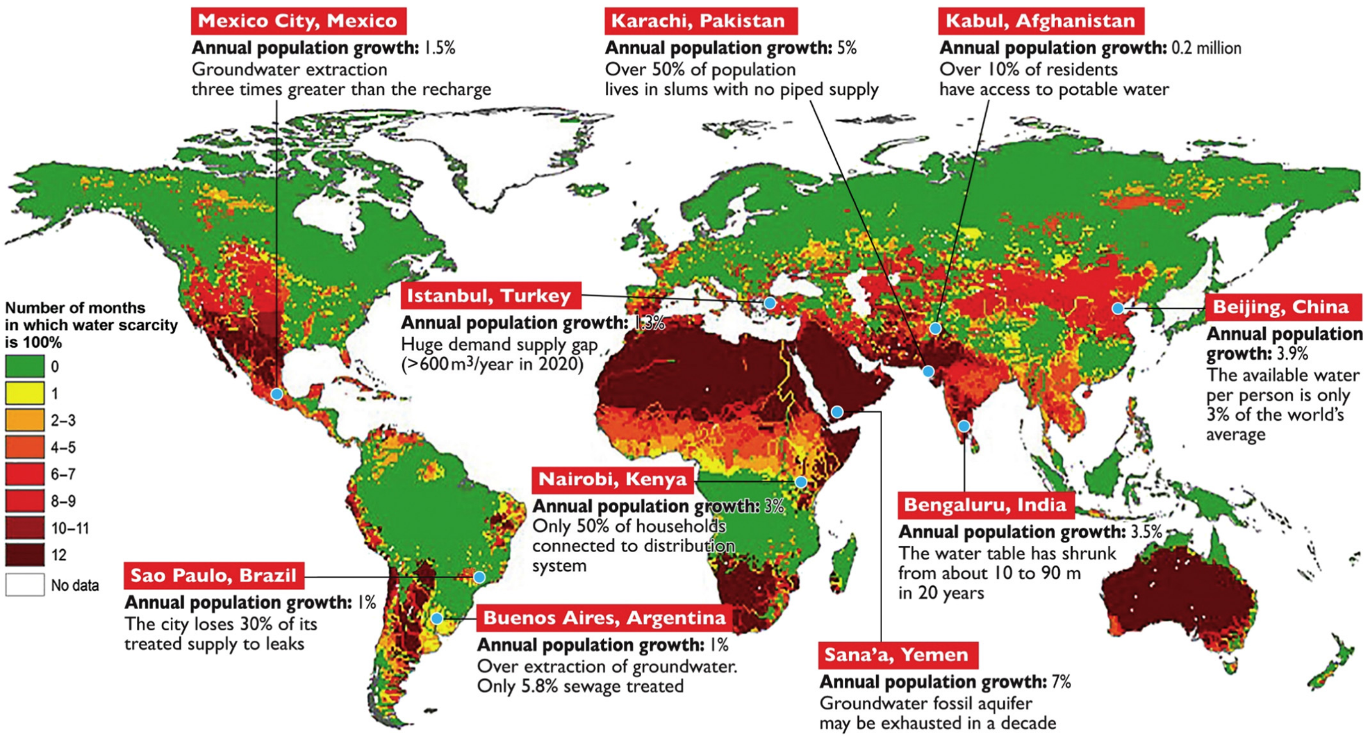


Fig. 1. Global blue water (surface water + groundwater) scarcity and cities facing imminent water crisis. Adapted from Mekonnen and Hoekstra (2016), under a Creative Commons license, and modified from Sengupta (2018), with permission from *Down to Earth*, India.

the local conditions due to their lower cost (Table 2) and water requirement. The Philippines, Malaysia, Senegal, Burkina Faso, and South Africa are a few examples of such countries (Cairns-Smith et al., 2014; Fig. 2). However, leakage from and overflow of septic tanks can result in groundwater and surface water contamination (Table 1). Management of septage from the septic tanks is also an issue, as discussed below.

2.3. Septage management

As urban areas rapidly expand, new settlements at the periphery of an urban area often lack water supply and wastewater treatment infrastructure. These habitations either depend on groundwater or informal water vendors using tankers to meet their daily water demand. For

Box 1
India case study.

India, the second-largest economy in Asia and the fifth largest in the world has witnessed rapid growth around its urban centres and plans to become a USD 5 trillion-dollar economy by 2023. Opening the Indian economy to the larger global market has led to rapid growth and an increased rate of people migrating from rural areas to the cities and towns for availing opportunities. At present, 37% of the total population of India resides in urban areas, which is projected to increase to about 50% by 2030 (MoUD, 2017).

Unplanned and rapid urbanisation has led to the creation of urban slums and shanties to house the urban poor that are devoid of necessities, including water and waste disposal. As per the census of 2011, 65.5 million or 22.5% of the population lives in such slums that are distributed across 2613 towns/cities. These slums generally lack basic water and sanitation facilities leading to unhygienic conditions that often are the cause of various diseases. Both communicable and non-communicable diseases within the population living in slums are the result of scarce clean water, low education and physical (in)activity (Ganguly, 2019; Lumagbas et al., 2018).

According to the 2011 Census of India, 68.8% of India's population lived in villages; among those, only 32.7% of the households had access to toilets (GOI, 2011). The Government of India launched a nation-wide mission, Swachh Bharat Mission (SBM), in 2014 to address the issue of open defecation. As a result, 102 million toilets were constructed, and rural sanitation coverage increased to 98.8%. Simultaneously for urban sanitation, 5.9 million individual household, community, and public toilets were constructed. Based on this, some rural 699 districts and 3461 towns/cities were declared as open defecation free (ODF). Despite this, a part of the urban population still practices open defecation, e.g. by 12.6% of the urban poor living in slums. In addition to this, only 87% of the total urban population has access to either household or community toilets. The data on the wastewater collection and disposal system shows that the sewerage system connects about 32% of the total urban population of 377 million. Sewerage systems being old and faulty often cause contamination of both groundwater and piped water. Every year several incidences of waterborne diseases are reported in the metro cities (Satapathy, 2014).

Recent initiatives such as ODF villages/towns/cities, however, have started to show a significant reduction in Acute Diarrheal Disease (ADD). In the year 2018, the total ADD outbreaks in several states of India were 46% which is significantly lower than that of the regular range of outbreaks in the peak season (Dandabathula et al., 2019). While millions of new toilets have been built in recent years, more investments are now needed to link these toilets with a functional sanitation service chain.

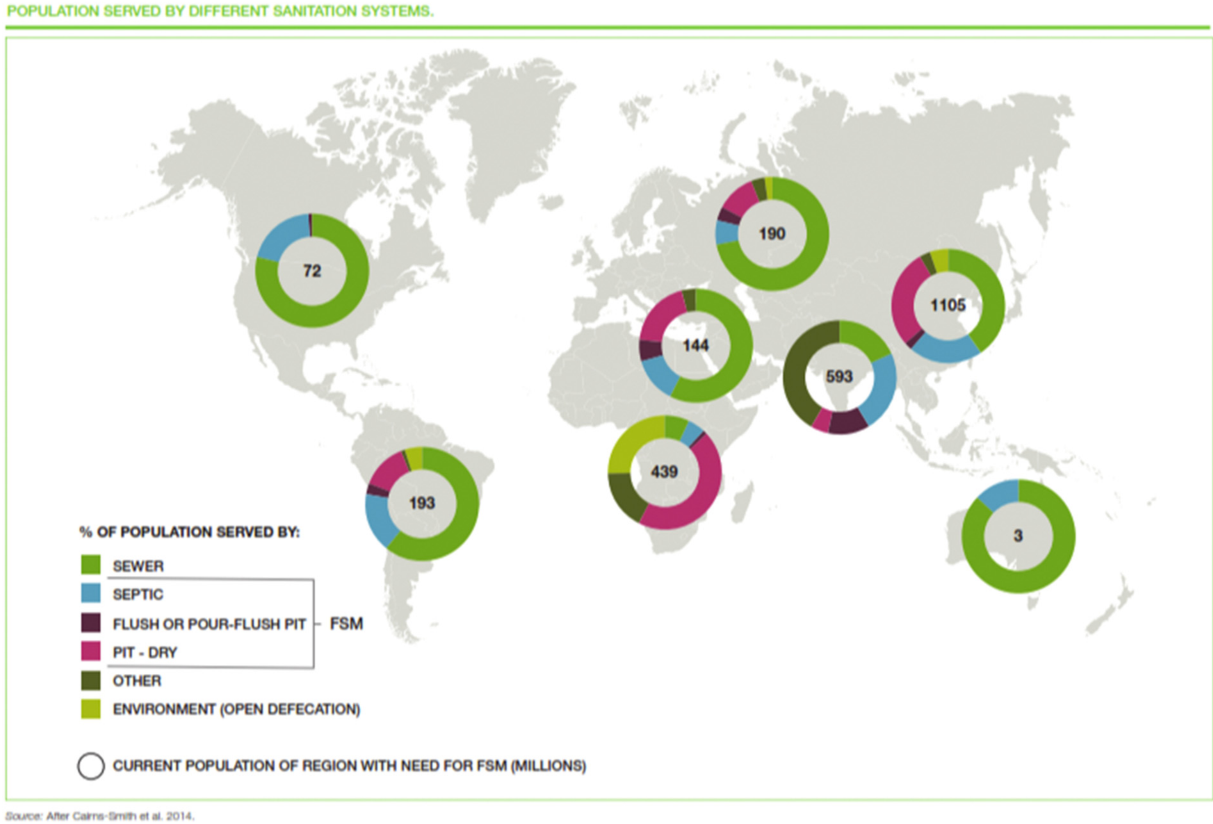


Fig. 2. Population served by different sanitation systems (Source: Rao et al. (2016) after Cairns-Smith et al., 2014). FSM stands for faecal sludge management – a term used for collection, transport and treatment of such sludge from pit laterines, septic tanks and other on-site systems.

blackwater disposal, OSS using soak pits or septic tanks is most common, while greywater is directly disposed of into open drains. For example, in the city of Bengaluru (India), 55% of households depend on groundwater through deep borewells to meet their drinking water demand and have OSS to dispose of blackwater (CGWB, 2013; Grönwall et al., 2010). The frequency of septic tank management varies largely between theory and practice. In many cases, desludging services are only ordered when tanks are full and overflow, rather than at regular time intervals to prevent such overflows. In a recent survey in Bhutan, Dorji et al. (2019) found that >80% of Bhutan's urban population relies on OSS and these are often without a soak-pit for disposal of wastewater. The lack of soak-pit resulting in overflow issues was flagged by the largest number of respondents (40–48%) as the key issue with OSS. Facilities for septage removal, such as a vacuum truck, were available only in about half of the 35 towns surveyed. While such studies are not commonly available, the scenarios are expected to be widely applicable to other low- to middle-income countries. For example, it is a common site in India to see privately operated vacuum trucks cleaning out septic tanks without any accepted way of treating septage. However, it is uncertain where the septage goes, but evidence from Bengaluru suggests some application to fertilize agricultural lands, if not discarded into nature. A similar situation is likely to exist in other low-income countries and emerging economies of Asia and Africa as dedicated septage treatment plants remain an exception (Rao et al., 2016).

USAID (2010) found that in South and South-East Asia only a small fraction of the septage collected from septic tanks was treated (0–5%) with the exceptions of Malaysia, where 100% of the septage was treated, and Thailand (30% treatment). In India there was no treatment of the septage from >160 million septic-tank based OSS (USAID, 2010). Poor septage management results in significant contamination of urban water resources, receiving environments such as rivers and groundwater and poses a risk to public health (Prakash and Somashekar, 2006; Ramesh et al., 2012; Shi and Kone, 2010; Vijay et al., 2010).

It is noteworthy, however, that several countries (e.g. India, Vietnam and the Philippines) have been increasingly recognising the importance of septage management. To close the sanitation loop and to reduce risk to human health, the Government of India has now formulated the policy for Faecal Sludge and Septage Management (FSSM). The Government of India has adopted the Service Level Benchmarking (SLB) framework to assess the performance of citywide sanitation capturing data on against standard performance indicators, such as the coverage of toilets and wastewater collection efficiency (Jaladhi et al., 2016). The overall objective is to reduce the incidence of disease through safe and sustainable FSSM service.

Table 2
Comparison of capital and operational costs of different sanitation systems (Cairns-Smith et al., 2014).

Type of sanitation option	Capital costs ($/person)		Annual operating costs ($/person/yr)
	Project costs assuming all targeted customers connect	Actual costs based on annual connections to network	
Centralized conventional sewer-based system	130–330	220–940	12–28
Decentralized simplified sewer-based system	105–155	105–155	4–10
On-site septic tank-based system	70–360	70–360	4–12

For sustainable solutions, infrastructure development and maintenance should go hand in hand. The latter requires training and capability development, in the absence of which the developmental initiatives fail. For example, in the 1990s some 150 septage treatment plants were built by the government in Indonesia and 90% of these were non-functional at the time of the USAID study (USAID, 2010). In a similar assessment across Ghana (Murray and Drechsel, 2011), <10% of the 70 identified sewage and septage treatment plants were operating effectively. The situation looked relatively better in India, where out of the total 816 municipal sewage treatment plants listed across India, 522 were operational (but only 64% functioning), 79 non-operational, 145 under construction, and 70 new STPs in construction (CPCB, 2015).

2.4. Wastewater treatment and disposal

Globally, over 80% of wastewater is released to the environment without adequate treatment (WWAP, 2017). However, there is significant variability across regions. For example, while 71% of municipal and industrial wastewater receives treatment in Europe, it is estimated that in Middle East and North Africa 51% and Latin America only 20% of such waters are treated (WWAP, 2017). Once discharged into water bodies, wastewater is either diluted, transported downstream or infiltrates into aquifers, where it can affect the quality (and therefore the availability) of freshwater supplies (Corcoran et al., 2010; WWAP, 2017). In 32 out of 48 countries in Sub-Saharan Africa, there is no data available on wastewater generation or treatment (Sato et al., 2013). The overall lack of infrastructure for wastewater collection and treatment in Sub-Saharan Africa results in significant pollution of often-limited surface and groundwater resources. The treatment situation is better in urban India, where out of the total 62 million cubic meters per day (MLD) wastewater generated, 37% receives secondary treatment. However, more wastewater gets generated than collected and more collected than eventually treated. Amerasinghe et al. (2013) estimated for 900 Class-I cities and Class-II towns in India that wastewater generation is 60–70% greater than the existing treatment capacity.

In peri-urban towns and rural areas, blackwater is disposed of in soak pits/septic tanks whereas the greywater from kitchens, laundry and bathrooms is directly discharged into stormwater drains. Such practice of wastewater disposal has led to the contamination and eutrophication of local water sources. Data from a global water quality monitoring program indicates that about one-third of all river stretches in Africa, Asia and Latin America are affected by severe pathogen pollution (WWAP, 2017). Several studies have reported the presence of faecal coliforms and nitrates in groundwater of peri-urban towns in India (Ahada and Suthar, 2018; Elangovan et al., 2018). Similar studies have reported the presence of high Chemical Oxygen Demand (COD) and phosphorus in surface water bodies in Sub-Saharan Africa (Silva et al., 2017). The disposal of untreated wastewater and septage to surface water bodies has led to the loss of aquatic flora and fauna in river stretches across urban areas (Sinha and Khan, 2001). Some recent episodes of fire and foam in one of the largest lakes of Bengaluru (India) highlights the need for wastewater treatment both at the local and the regional scale (Abraham, 2018).

2.5. Food security

2.5.1. Peri-urban agriculture

Significant population growth is expected in urban and peri-urban areas of developing countries, thus exacerbating both the competition for scarce water resources and the production and management of urban wastes (WHO, 2006). The role of urban agriculture in global food security is a topic of increasing discussion. On one hand, there is an increasing call for 'local food'. On the other hand, food safety can be a significant issue where this food is exposed to contaminants via irrigation with untreated or poorly treated wastewater. In countries where wastewater treatment is insufficient, the use of polluted irrigation supply is common.

Developed countries treat the majority of wastewater produced, regardless of the motivation for reuse for irrigation or for environmental protection during waste disposal (Sato et al., 2013). In contrast, in developing countries where <10% of wastewater is treated, the lack of cold transport supports the widespread growth of urban and peri-urban farming to produce easily perishable vegetables. This need for all-year water supply is as important as the need for water where water is generally scarce, i.e. wastewater irrigation is not limited to arid to semi-arid areas (WWAP, 2017). While the year-round vegetable supply is of benefit for many urban areas, the same population is at risk of pathogenic exposure. In the case of Ghana, these are about 700,000 urban dwellers daily (Drechsel and Seidu, 2011).

Developed countries facing water supply solutions, such as Australia, provide guidance on safe and sustainable wastewater irrigation (NRMMC-EPHC-AHMC, 2006). Wastewater from South Australia's major wastewater treatment plant is treated to provide 'Class A' recycled water for irrigation of over 5400 ha horticulture on the Northern Adelaide Plains which produces around 204,000 tomes of fresh produce per annum which is valued at over AUD$313 million (Vanderzalm et al., 2019).

2.5.2. Impact of irrigation with untreated or poorly treated wastewater

The primary human health risk associated with wastewater use is from microbial pathogens that can result in disease outbreak, but there are also concerns regarding the chronic health effects associated with toxic chemicals that may be present in wastewater (WHO, 2006) (Table 3). In addition to human health risks it is also necessary to protect against environmental risks associated with wastewater irrigation such as groundwater and soil contamination, by adopting strategies to optimise water reuse and maintain soil productivity (Valipour and Singh, 2016). Salinity, boron, chloride, sodium and chlorine disinfection residuals (for treated wastewater) are all key risks to crop production and soil health (NRMMC-EPHC-AHMC, 2006; NRMMC-EPHC-NHMRC, 2009). Also, the increase in water salinity in sun-exposed treatment ponds can drive farmers, e.g. in Faisalabad, Pakistan, back to the use of untreated wastewater (Ensink et al., 2007). Increased chloride concentrations due to wastewater irrigation can make native cadmium in soils more readily available to plants and result in plant toxicity impacts. Nitrogen and phosphorus in raw and undiluted wastewater can reduce the need to use fertilizer, but nutrient imbalance in plants and eutrophication of soils are environmental risks to be considered (Qadir et al., 2010).

The above issues associated with food and water security in emerging economies deserve urgent attention. There are a variety of potential solutions that could be considered to address these, as described below.

3. Potential solutions

3.1. Rural-urban water link and the role of wastewater

To address urban water deficits, cities compete with crop irrigation in rural areas. With increasing population growth, demands for higher protein diets and biofuels will require a significant increase in agricultural output, which can only be met through greater water use in farming. This will accelerate the over-exploitation of our freshwater resources, including a 66% increase in non-renewable groundwater withdrawals which is likely to affect millions of people by 2030, and billions by the end of the century (GWI, 2014).

Direct and indirect water reuse can play a key role in meeting the water and food needs of people around the world and demonstrates the need to invest in wastewater treatment to protect public health and livelihoods (Thebo et al., 2017). The global area of urban irrigated croplands was estimated at about 24 Mha, or about 11% of all irrigated croplands. The total area of irrigated peri-urban croplands within ten

Table 3
Potential impacts of constituents in untreated or poorly treated wastewater to human health and the environment (after NRMMC-EPHC-AHMC, 2006; Drechsel et al., 2010).

Constituent	Potential impact		Geographical relevance
	Positive	Negative	
Pathogens (bacteria, viruses, protozoa, helminths)	None	Communicable diseases through ingestion of wastewater or consumption of food product	Particularly in low-income countries where sanitation is poor
Salinity and major ions (TDS, Na, Ca, Mg, Cl, B)	Ca in wastewater can improve soil structure and mitigate impacts of wastewater irrigation	Deterioration of soil structure and reduction in soil hydraulic conductivity and infiltration rate Reduction in crop yield Contamination of receiving environment	Particularly in arid and semi-arid areas with high primary salinity and large-scale wastewater irrigation occurs and drainage is poor or where saline drainage water is reused in irrigation
Macronutrients (N, P, K)	Reduce need for chemical fertilizers	Nutrient imbalance in plants Pest and disease in plants Contamination of receiving environment – resulting in eutrophication or high nitrate in drinking water Biological growth and clogging of irrigation equipment or soil	Particularly in low-income countries where wastewater is untreated or poorly treated
Organic matter	Can improve soil structure Can bind metal ions rendering them less available for plant uptake	Biological growth and clogging of irrigation equipment or soil Stimulate redox reactions (i.e. leading to hypoxic conditions in surface waters)	Particularly in low-income countries where wastewater is untreated or poorly treated
Metals and metalloids	Reduce need for micronutrient fertilizers	Reduction in crop yield Possibly toxicity in humans and animals Contamination of receiving environment	Particularly in low-income countries where wastewater is untreated or poorly treated
Emerging contaminants of concern (e.g. endocrine disruptors, pharmaceutical, personal care products and complex mixtures)	None	Contamination of receiving environment (i.e. groundwater) Potential human health risk	Greater concern in developed countries where use of pharmaceuticals and personal care products is higher

and 20 km range of urban areas is 87 and 130 Mha, respectively (Thebo et al., 2014). About 29 Mha of downstream irrigated croplands are in catchments with high levels of dependence on urban wastewater flows and low levels of wastewater treatment, home to 885 million urban residents.

Estimates for India show, for example, that treated urban wastewater could safely irrigate between 1 and 3 million hectares (ha), depending on the type of crop cultivated and its irrigation requirement. This wastewater irrigation potential is nearly three times the surface water-based minor irrigation potential created in India's 10th five-year plan (WSP and IWMI, 2016; Amerasinghe et al., 2013). Estimates for Ghana's capital Accra show that irrigated urban agriculture recycles up to 10% of Accra's domestic wastewater (entering urban streams), making the farming sector a larger informal 'treatment' service provider compared to that offered by municipal treatment plants (Lydecker and Drechsel, 2010).

How could cities cope under rural-urban competition, including non-coastal cities and those where inter-basin transfers would be too costly? There are different options:

- With declining groundwater levels, the most common but unsustainable urban response is to exploit peri-urban surface and groundwater resources which can quickly result in rural-urban conflicts and tensions, as seen for example in the case of Chennai where local residents were blocking roads and laying siege to tankers to protect their water resources (Varadhan, 2019). A similar resistance against industrial expansion was reported earlier from Uttar Pradesh (Chaudhary, 2014), calling for an integrated approach to land-use planning and zoning, which includes water as a key aspect (NITI Aayog, 2019).
- A smarter option for cities could be to invest in agricultural water use efficiency, by supporting farmers to reduce water losses/leaks, change their irrigation technologies and practices through education on when and where to irrigate and grow less water-intensive crop varieties. A 10% improvement in agricultural water-use efficiency could free up enough water for urban use in 80% of the high-conflict urban sub-basins (Flörke et al., 2018). In Cape Town, for example, larger farmers adopted water efficiency measures and were able to donate 10 Mm^3 from their reservoirs to the city to help prevent "Day Zero".
- Optimizing rural-urban water use efficiency needs an inter-regional approach. In Punjab, India, for example, nearly 100% of the rice grown is irrigated. As a result, Punjab tops the table in land productivity, but uses more than three times the water use in Bihar and more than twice the amount of water use in West Bengal, to produce 1 kg of rice while groundwater reserves are declining (NITI-Aayog, 2019). Business models that bank on wastewater reuse, link rural and urban water demands, and bridge between drinking water and agricultural needs have been studied by Otoo and Drechsel (2018). These models are based on rural-urban water trading, as realized elsewhere e.g. in Iran and Spain. Compared with inter-basin water transfers, the swap models target inter-sectoral transfers of water to uses of higher economic value, i.e. water originally allocated to agriculture is transferred to domestic use, especially for drinking water. The models involve a two-way flow, i.e. freshwater release and transfer are compensated for by releasing (treated) wastewater able to replace the created water gap on farm and support if needed also other ecosystem service functions (Box 2).

3.2. Safe reuse of wastewater: public and ecosystem health

In low/middle-income countries and emerging economies with limited wastewater treatment, an increasing challenge for urban food security is informal wastewater reuse and related public health risks. A key challenge for the reuse sector is to make the significant area of informal

Box 2
Rural-urban water swap.

In the case of the Llobregat delta in Spain, a severe drought in 2007/8 resulted in an economic loss of EUR 1.6 billion and catalyzed significant investments into infrastructure able to produce high-quality recycled water to secure farmers' acceptance of an up to 20 Mm^3 water swap in prolonged periods of drought. For this, the water swap contract remained flexible to allow transfers and volumes as needed (Otoo and Drechsel, 2018).

In Iran, on the other hand, the urban water deficit of the city of Mashhad is common reality and farmers in Mashhad plain received incentives to transfer their freshwater rights to the city in exchange for treated wastewater. While initially, all city dwellers supported the planned exchange, about 97% of water right holding farmers opposed the plan (Yazdi, 2011). In 2006, farmers started to release annually about 21 Mm^3 of freshwater from two dams, in exchange for 25 Mm^3 of treated wastewater based on a fixed contract between water right holding farmers and the Regional Water Company. While in this case the political power of the urban sector determined the negotiations, the opposite could be possible, like in the case of Chakera, Pakistan, where farmers strongly preferred (untreated) wastewater to unreliable and nutrient-poor freshwater (Otoo and Drechsel, 2018).

irrigation using untreated wastewater directly or indirectly safer (ca. 30 million ha), along with increasing the area under formal reuse of treated wastewater (SDG 6.3) which is globally <1 million ha (Thebo et al., 2017; IWMI, unpublished). To address this challenge, investment in treatment capacity has to be combined with the WHO promoted "multi-barrier" safety measures between farm and fork (WHO, 2006; Amoah et al., 2011). Investments in these options can save US$ 5 in consumer health care for every dollar spent on risk reduction (Drechsel and Seidu, 2011). However, a formal adoption of the WHO (2006) guidelines remains limited till now. A successful move from informal to formal reuse is largely an institutional challenge, targeting increased awareness and (positive and negative) incentives for change. Examples of incentives could be higher land security for informal urban farmers, training, certification schemes (awards) for safe farming, access to loans or subsidies etc. (Karg and Drechsel, 2011; Saldias, 2016). Positive incentives are most important where regulations are not able to enforce change e.g. crop restrictions in the informal irrigation sector. Attempts, to arrest urban farmers using wastewater on leafy vegetables, like in Accra, Ghana, failed given the large number of farmers, and urban demand for the crops (Drechsel and Keraita, 2014).

Safe and productive use of wastewater for irrigation relies on preventative measures to manage contaminants that may pose a risk to human health through consumption of produce, or to the environment through soil or crop impacts. Wastewater treatment and exposure control are the key preventative measures used, and WHO (2006) emphasizes that there is a range of more cost-effective non-treatment options between farm and fork (i.e. exposure controls), as tested extensively e.g. in Ghana (Amoah et al., 2011; Drechsel and Seidu, 2011). The challenge remains that safety interventions require (incentives for) behavioural change (Karg and Drechsel, 2011) and treatment infrastructure development is being outpaced by urban growth (Sato et al., 2013).

Risk assessment and management facilitate the safe use of wastewater for agriculture (WHO, 2006; NRMMC-EPHC-AHMC, 2006; NRMMC-EPHC-NHMRC, 2009). This applies to intentional use of wastewater for irrigation, but also to the use of surface water resources that may be subject to faecal contamination (WHO, 2006), such as rivers receiving sewage waste with little or no treatment. Specific risk-based guidelines have been developed to maximise public and environmental health protection, while utilizing alternative water resources for food production (FAO and WHO, 2019). It is also essential to manage risks to farmers, consumers and the environment from domestic and industrial water pollution of surface water supplies traditionally used for irrigation. This applies to many rivers carrying at best partially treated sewage to downstream farming regions, where conventional perceptions, terminology and quality standards might not account for the possible risks.

Risk management involves establishment of health-based targets for pathogen removal which are relevant for the intended use. For example, health-based targets for irrigation of food crops that are consumed raw or unprocessed are more stringent than for non-food crops. Importantly, these health-based targets can be met with preventative measures such as wastewater treatment and/or through health protection measures such as exposure control (e.g. produce washing, disinfection and cooking; crop restriction) (Amoah et al., 2011; FAO and WHO, 2019).

3.3. Water quality monitoring

Risk management relies on three types of monitoring: validation, operational and verification monitoring (WHO, 2006; NRMMC-EPHC-AHMC, 2006; NRMMC-EPHC-NHMRC, 2009). Validation monitoring is used to prove the system is capable of meeting performance targets. Operational monitoring is routine and rapid monitoring that can be used to inform management decisions, such as turbidity or electrical conductivity that can be measured continuously. Verification monitoring is done regularly to check the preventative measures put in place for risk management are performing as intended.

Water quality indicators are a key component of verification monitoring and are considered to represent a broader group of hazards, rather than monitoring each hazard directly. For example, health-based targets for pathogen removal are not verified by measuring specific pathogen numbers, but instead by a pathogen indicator organism, such as *Escherichia coli* (*E. coli*) (WHO, 2006). Water quality monitoring is likely for large wastewater treatment plants and irrigation supplies, but less likely or practical in small or informal applications of wastewater irrigation or where water quality analysis capability is absent. In these cases, operational and verification monitoring can be based on visual inspections (i.e. irrigation type, crop restriction) and public health information, rather than water quality monitoring (WHO, 2006).

Australian guidelines for water recycling via aquifers have been used extensively within the Australian context for over a decade (NRMMC-EPHC-NHMRC, 2009), but have also been reported as having onerous data requirements (Dillon et al., 2020). For application in countries where capability for water quality monitoring, sampling and analysis may be limited Dillon et al. (2020) recommends using visual observations where applicable to support risk-management until capability for water quality monitoring develops.

3.4. Water-wise, low-cost and sustainable systems

Water sensitive urban design (WSUD) is consideration of the natural water cycle to allow maintenance of natural flows in urban planning and development. WSUD is also referred to as low impact development, green infrastructure or sustainable urban drainage systems (Sharma et al., 2018). WSUD goals can be flood protection in response to increased coverage of impervious surface but also for water harvesting

(Hamlyn-Harris et al., 2019). Roof water and stormwater harvesting, alone or in combination with managed aquifer recharge (see below), are examples of WSUD that can provide sustainable water supply solutions for developing countries.

Managed aquifer recharge (MAR) refers to the intentional recharge of water to aquifers for subsequent use or environmental benefit. MAR's benefits include low-cost, low-energy water supply, improvement in water quality through natural treatment, minimization of losses through evaporation and replenishment of over-exploited aquifers. MAR plays an important role in integrating the management of surface and groundwater resources for year-round security of water supply while ensuring public health and environmental protection. The uptake of MAR for water management has grown over the past 60 years, and currently it is estimated at 10 km^3/year (Dillon et al., 2019). India has the greatest capacity for MAR with several million individual recharge structures (Dillon et al., 2019). In Australia, MAR with treated wastewater, urban stormwater and surface water is projected to grow rapidly over the next 50 years due to the expectations for population growth and the subsequent demand for water and food alongside increased wastewater generation (Fig. 3, Dillon, 2015).

MAR with stormwater or treated wastewater can take advantage of natural treatment processes in the unsaturated zone and the aquifer to produce water suitable for agricultural and/or domestic (non-potable) reuse. In general, infiltration-based MAR, such as soil aquifer treatment (SAT), is the most cost-effective means of recharging groundwater for agricultural use (Bekele et al., 2018). The effectiveness of treatment depends on local conditions (in particular, wastewater quality versus soil depth and characteristics) and operating procedures, but SAT has been reported to provide up to 7-log removal of bacteriophage in 30 m of subsurface travel (Maliva, 2019). In developed countries SAT is typically applied as a tertiary treatment step, recharging wastewater that has been through primary and secondary treatment or a stabilization pond (Maliva, 2019) based on well-established quality criteria (e.g. Dillon et al., 2014; Alcalde-Sanz and Gawlik, 2017). While there are examples of MAR with treated wastewater in developed countries (e.g. Australia, USA), replenishing aquifers with untreated wastewater is more common in less-developed countries where engineered wastewater treatment capacity is low. As urban dwellers pay more than farmers, the regained water is often transferred back to the city and not farming (Box 3).

Box 3
Peri-urban areas as ‘kidneys’ for urban water needs.

In the example from Bangalore, India, largely untreated wastewater is transferred out of town to replenish the peri-urban Amani Doddakere tank and its aquifer, resulting in multiple benefits for farming and ecosystem services. An extension of the model to 38 other lakes has been proposed to improve urban groundwater supply by 180,000 m^3/d. Already, some of the recovered water returns to the city through informal water markets, at prices which are unaffordable for poorer households. Such rural-urban water transactions are increasingly common around many cities in India and need much stronger official acknowledgement to address likely health risks.

In the example of the Mezquital Valley of Mexico, which is well-known for large scale wastewater reuse (Jiménez and Asano, 2008), the recent inauguration of the Atotonilco Treatment Plant will support the recovery of 160–190 Mm^3/year for Mexico City from the bursting Mezquital aquifer due to lower pumping costs than any alternative water transfer option (Otoo and Drechsel, 2018).

For emerging economies, it is crucial that the solutions are not only low-cost but also offer added advantages that ensure sustainability i.e. contribute to food security, generate livelihood and help pay for infrastructure and running costs. In addition to the solutions originating from the developed world, some established approaches that may be adapted to local needs to ensure safety of public and ecosystem health are worth considering. The East Kolkata Wetlands (EKW), a Ramsar wetland system (12,500 ha) has been supporting the treatment of the city's wastewater as well as the production of fish, vegetables and rice for >50 years (Bunting et al., 2010). The wetlands produce 10,000 t of fish and 40–50% of the green vegetables available in the Kolkata markets. While the system has been noted to be resilient, its suitability from the standpoint of public health safety and ecosystem contribution needs to be fully evaluated. Fish farming in constructed wastewater treatment ponds is also reported

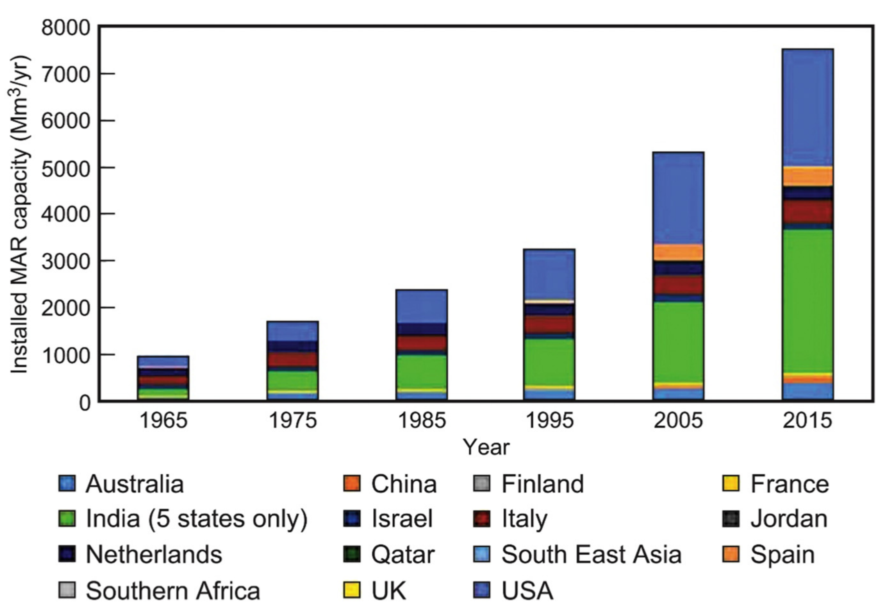
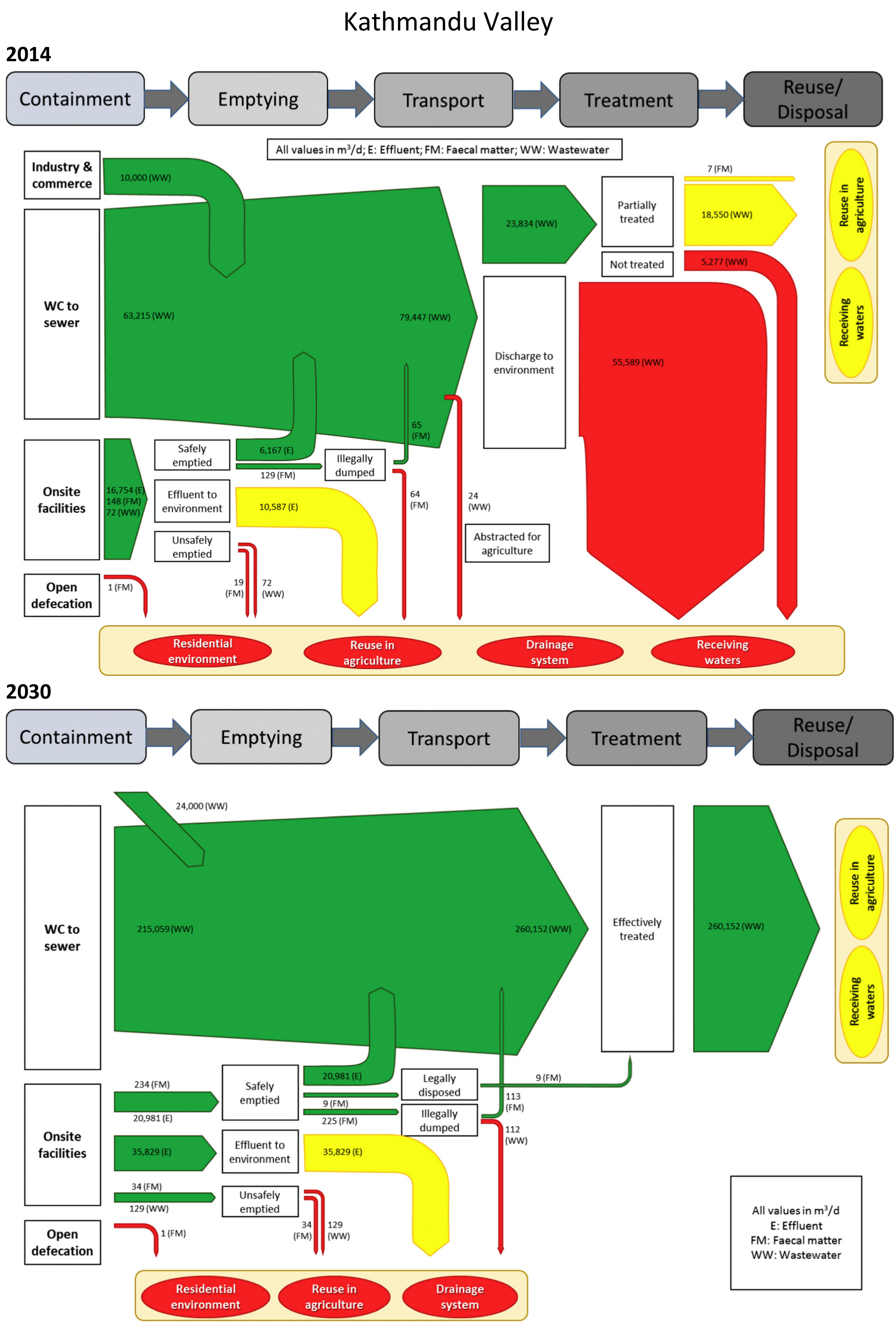


Fig. 3. Evolution of Managed Aquifer Recharge (MAR) capacity in different countries from 1960 to 2000 and 2011–2015 (taken from Dillon et al., 2019). Note: Bar stacks from bottom up follow the alphabetical order of countries as per the legend.


Kathmandu Valley
2014
Containment
Emptying
Transport
Treatment
Reuse/ Disposal
All values in m³/d; E: Effluent; FM: Faecal matter; WW: Wastewater
Industry & commerce
10,000 (WW)
WC to sewer
63,215 (WW)
79,447 (WW)
23,834 (WW)
Partially treated
Not treated
7 (FM)
18,550 (WW)
5,277 (WW)
Discharge to environment
55,589 (WW)
Reuse in agriculture
Receiving waters
Onsite facilities
16,754 (E)
148 (FM)
72 (WW)
Safely emptied
6,167 (E)
129 (FM)
Illegally dumped
65 (FM)
Effluent to environment
10,587 (E)
64 (FM)
24 (WW)
Unsafely emptied
19 (FM)
72 (WW)
Abstracted for agriculture
Open defecation
1 (FM)
Residential environment
Reuse in agriculture
Drainage system
Receiving waters
2030
Containment
Emptying
Transport
Treatment
Reuse/ Disposal
24,000 (WW)
WC to sewer
215,059 (WW)
260,152 (WW)
Effectively treated
260,152 (WW)
Reuse in agriculture
Receiving waters
Onsite facilities
234 (FM)
20,981 (E)
Safely emptied
20,981 (E)
9 (FM)
225 (FM)
Legally disposed
9 (FM)
Illegally dumped
113 (FM)
112 (WW)
35,829 (E)
Effluent to environment
35,829 (E)
34 (FM)
129 (WW)
Unsafely emptied
34 (FM)
129 (WW)
Open defecation
1 (FM)
Residential environment
Reuse in agriculture
Drainage system
All values in m³/d
E: Effluent
FM: Faecal matter
WW: Wastewater

in Ghana where precautionary measures such as fish cooking/grilling prior to consumption are recommended. In Bangladesh, fish production was able to cover all costs of the local wastewater treatment system.

Creating infrastructure alone is not a sustainable solution to the problem, as despite the initial top-down investments by governments in infrastructure, the lack of grassroot training, capability and support in sustaining these means often most of such systems fail (Eales et al., 2013). About 70% of sanitation systems fail within two years of construction, for various reasons (Davis et al., 2019).

3.5. A new way of faecal matter management

As discussed earlier, faecal matter/excreta management is a major challenge in cities and towns in emerging economies, and it can result in significant adverse impact on public and environmental/ecological health. In this regard, Shit Flow Diagrams (SFDs) have emerged as a new way of understanding and visualising excreta management in cities to facilitate planning interventions/ solutions with specific goals in mind. Besides these could prove as an effective communication and engagement tool between city planners and sanitation practitioners. As evident from the global SFD project (https://sfd.susana.org/) there is now a growing list of SFDs being developed for cities around the world (> 100 in April 2020) and especially in the emerging economies. Here we provide a specific example from Nepal, that is yet to be added to the above global SFD repository (Fig. 4).

Kathmandu, together with the surrounding cities and towns of Lalitpur, Bhaktapur, Madhyapur Thimi and Kirtipur, form the largest urban agglomeration in Nepal. Although most of the faecal matter and wastewater is safely captured at the containment stage, only a fraction makes it safely through the entire sanitation chain (Fig. 4). The SFD for 2014 shows that a vast majority of excreta is currently discharged to the environment without treatment. With the support of different development partners, several significant initiatives are under way to improve the wastewater management situation in Kathmandu Valley. If all goes as planned, the situation in 2030 could be substantially improved. SFDs such as these can be used to visualize projected and actual progress in excreta management.

3.6. Behavioural change

Behavioural change is essential for sustainable urbanisation into the future in both developed and developing countries. Community attitudes form the foundation of urban design, as the design parameters in cities are informed by community behaviours and expectations. It is interesting to compare that while currently the cities in North America are designed with 300 L/pers./day criteria, in Morocco the design parameter used is as low as 70 L/pers./day (Trommsdorf, 2020). From the wastewater treatment perspective, while the US systems are designed with 60 g BOD_5/pers./day the European systems aim at 80 g BOD_5/pers./day. In Asia, Thailand uses even lower design criteria of 40 g BOD_5/pers./day. This clearly reflects the culture and behaviour of respective urban populations and demonstrates potential scope for improvements. Under adverse conditions, such as during Millennium Drought in Australia and under extreme water scarcity in Cape Town, a marked decline in daily per capita consumption of water was realized by changing the community behaviour through an increased appreciation of the sense of water crisis (Lindsay et al., 2017).

In addition to the institutional reform and financial incentives, the potential role of behavioural change in managing the demand for water and food in cities needs to be recognised more strongly. Additionally, behavioural change in the disposal of chemicals and wastes, as well as community understanding of health risks and approaches to manage risks associated with wastewater reuse (such as the farm to fork approach) are required. Through a controlled trial in a peri-urban community in Lusaka (Zambia), Tidwell et al. (2019) demonstrated that behavioural intervention alone (independent of institutional/financial incentives) can improve the structural quality and cleanliness of shared sanitation. Community engagement and grassroot movements in water conservation, water reuse and recharging of groundwater resources are necessary ingredients for a sustainable urbanisation of future. Lindsay et al. (2017) report that active participation in water management is more likely when citizens are engaged with water and have good knowledge of the issue. In a comparison of three cities in Australia facing the Millenium Drought, water conservation behaviours were greater in the two cities with a sense of water crisis than in the third city with access to alternative water supplies (desalination, groundwater) (Lindsay et al., 2017). For example, community engagement was achieved to improve groundwater management in India by providing groundwater education at village scale through *Bhujal Jankaars* (BJs), schools, workshops and newsletters (Maheshwari et al., 2014). In Perth (Australia), community engagement was critical to the success of implementing water recycling via the aquifer to augment the drinking water supply (Bettini and Head, 2016).

3.7. Water apartheid

Water scarcity problems may shift from one region to the other. The virtual trade of water via food export was estimated to be 2320 Gm^3/y in 2012, which was about one fourth of the corresponding average global water footprint of humanity of 9087 Gm^3/y (Hoekstra and Mekonnen, 2012). Ghana's capital Accra, for example, receives its piped water from two basins (Volta and Densu). Eighty per cent of its food (and virtual water) supply comes from four basins in and around Ghana, and the remaining 20% from 38 basins worldwide, which illustrates the size of Accra's water footprint to satisfy urban demands (Drechsel et al., 2007). The actual transfer of water from rural areas to urban centres to meet the demand of urban populations is also significant. Garrick et al. (2019) estimated that 69 cities with a population of 383 million people (in 2015) receive 16 billion cubic meters of reallocated water per year. This can potentially create win-win, win-lose and lose-lose outcomes for donor and recipient regions which necessitates careful contractual agreements (Garrick et al., 2019).

The cases of Chennai and Cape Town created significant awareness on the increasing challenge to provide growing urban centres with enough water, a challenge with significant social and economic implications, which could ultimately lead to social segregation on grounds of access to water, i.e. ‘water apartheid’. Macdonald et al. (2014) estimated that the water-stressed large cities represent $4.8 trillion in economic activity. To sustain increasing urban water demand different strategies are common depending on local feasibility, including long-distance water transfer (Garrick et al., 2019), advanced wastewater treatment for reuse, and where possible seawater desalination. Commonly referenced examples of technical excellence are the production of potable water from wastewater in Singapore and Namibia, based on a business model that is largely dependent on reliable technology and positive public perceptions (Lazarova et al., 2013).

Fig. 4. Shit flow diagrams (SFDs) for Kathmandu Valley (Kathmandu Metropolitan City, Lalitpur sub-Metropolitan City, Bhaktapur Municipality, Madhyapur Thimi Municipality, and Kirtipur Municipality), reflecting the planned change from 2014 to 2030. The Draft SFD for 2030 is under consideration and is used here for illustration purposes only. Source: IWMI by Heather Purshouse and Grattan Maslin.

4. Recommendations

To facilitate the adoption of the options and solutions suggested above, it is important to address existing knowledge gaps via the following recommendations.

- **Water-wise sanitation systems:** Urban planners should carefully consider which on- or off-site sanitation systems would be water-wise as the city spreads. SFDs are a very useful tool for such planning.
- **Rural-urban water link and the role of wastewater:** Wastewater can play a key role in meeting the water and food needs of people around the world. However, better urban planning and novel approaches are needed to realise these potentials.
- **Reuse of poorly treated/untreated wastewater:** Much more attention must be given to the vast areas where untreated or only partially treated, diluted or even raw wastewater is already used in informal reuse.
- **Cost-effective and sustainable wastewater treatment:** Planners need to consider which combination of investments in wastewater treatment for reuse, desalination, long-distance transfer, and/or freshwater – wastewater exchange options with [upstream] farming communities, could be the most cost-effective and sustainable. Treatment should be provided through natural systems (wetlands, soil, aquifer) in combination with engineered treatment (e.g. disinfection) as required. Similarly, optimisation of reuse of adequately treated wastewater can enhance safe food production, improve water security, prevent surface and groundwater contamination and enhance livelihoods.
- **Water quality indicators:** Considering the lack of capability in emerging economies in water quality monitoring, such as for microbial contamination, appropriate water quality indicators must be developed to support risk management.
- **Community behavior change:** Community behavioural change is as important as institutional reforms and financial incentives. Behavioural intervention should form an integral part of urban design criteria. Besides understanding of health risks and approaches to manage risk (behavioural change), such as the farm to fork approach, is required.
- **Water apartheid:** Given the common scarcity of a 24/7 water supply in low- and middle-income countries and increasing number of cities which might face a “Day Zero”, there is a high risk of intensified social segregation (‘water apartheid’) that needs significant attention through pro-poor tariffs and water service policies.

5. Concluding remarks

The transformative power of urbanisation is undeniable, and urbanisation is clearly among the global megatrends of the 21st century. Adding 2 billion more people to urban areas in resource-limited regions of South Asia and Sub-Saharan Africa in the next three decades is bound to pose major challenges in terms of water and food security, waste management, sharing of wealth and resources (development of slums), among other impacts. UN SDG 6, to ensure availability and sustainable management of water and sanitation for all, will require a concerted effort globally. However, solutions for emerging economies must be tailored to the unique needs of the country/region and not just transferred from dissimilar geographies in the hope that these will work. Some of the solutions suggested in this paper are based on experiences from resource-limited regions. We hope the options and recommendations suggested above for addressing the challenges associated with rapid urbanisation in emerging economies in relation to UN SDG 6 offer a start in the right direction.

Declaration of competing interest

The authors along with all co-authors are in agreement for the work being peer reviewed and possibly published and we have no undeclared competing financial interests or conflicts of interest.

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References

Abraham, M.R., 2018. Toxic lake bursts into flames. Natl. Geogr. February 14, 2018. https://www.nationalgeographic.com/news/2018/02/bangalore-india-lake-bellandur-catches-fire-pollution/.

Ahada, C.P.S., Suthar, S., 2018. Groundwater nitrate contamination and associated human health risk assessment in southern districts of Punjab, India. Environ. Sci. Pollut. Res. 25 (25), 25336–25347. https://doi.org/10.1007/s11356-018-2581-2.

Alcalde-Sanz, L., Gawlik, B.M., 2017. Minimum Quality Requirements for Water Reuse in Agricultural Irrigation and Aquifer Recharge - Towards a Legal Instrument on Water Reuse at EU Level, EUR 28962 EN. Publications Office of the European Union, Luxembourg, p. 2017 ISBN 978-92-79-77175-0. https://doi.org/10.2760/804116 (JRC109291).

Amerasinghe, P., Bhardwaj, R.M., Scott, C., Jella, K., Marshall, F., 2013. Urban Wastewater and Agricultural Reuse Challenges in India. International Water Management Institute (IWMI), Colombo, Sri Lanka https://doi.org/10.5337/2013.200 36p. (IWMI Research Report 147).

Amoah, P., Keraita, B., Akple, M., Drechsel, P., Abaidoo, R.C., Konradsen, F., 2011. Low-Cost Options for Reducing Consumer Health Risks from Farm to Fork where Crops Are Irrigated with Polluted Water in West Africa. International Water Management Institute, Colombo, Sri Lanka (45p. (IWMI Research Report 141).

Barkham, P. 2016. The miracle of Kolkata's wetlands - and one man's struggle to save them. The Guardian Newspaper. https://www.theguardian.com/cities/2016/mar/09/kolkata-wetlands-india-miracle-environmentalist-flood-defence (last accessed 16 Dec 2019).

Bekele, E., Page, D., Vanderzalm, J., Kaksonen, A., Gonzalez, D., 2018. Water recycling via aquifers for sustainable water quality management: current status, challenges and opportunities. Water 10, 457. https://doi.org/10.3390/w10040457.

Bettini, Y., Head, B.W., 2016. WA groundwater Replenishment Trail: A case study of creating the enabling environment for regulatory change. Cooperative Research Centre for Water Sensitive Cities Ltd https://watersensitivecities.org.au/wp-content/uploads/2016/05/TMR_A3-1_WA_GroundWaterReplenishmentTrial.pdf.

Bunting, S.W., Pretty, J., Edwards, P., 2010. Wastewater-fed aquaculture in the East Kolkata Wetlands, India: anachronism or archetype for resilient ecocultures? Rev. Aquac. 2 (3), 138–153. https://doi.org/10.1111/j.1753-5131.2010.01031.x.

Cairns-Smith, S., Hill, H., Nazarenko, E., 2014. Urban Sanitation: Why a Portfolio of Solutions Is Needed. Working Paper. The Boston Consulting Group http://www.bcg.com/documents/file178928.pdf.

CGWB, 2013. Groundwater Information Booklet: Bangalore Urban District. Central Ground Water Board, Ministry of Water Resources, New Delhi.

Chaudhary, A., 2014. Farmers Fight Coca-Cola as India's Groundwater Dries Up. https://www.livemint.com/Politics/55tZIXk1ov2ADNcLnVZRwN/Farmers-fight-CocaCola-as-Indias-groundwater-dries-up.html.

Corcoran, E., Nellemann, C., Baker, E., Bos, R., Osborn, D., Savelli, H. (Eds.), 2010. Sick Water? The Central Role of Wastewater Management in Sustainable Development. A Rapid Response Assessment. United Nations Environment Programme, UN-HABITAT, GRID-Arendal www.grida.no.

CPCB, 2015. Inventorization of Sewage Treatment Plants. Government of India https://nrcd.nic.in/writereaddata/FileUpload/NewItem_210_Inventorization_of_Sewage-Treatment_Plant.pdf.

Dandabathula, G., Bhardwaj, P., Burra, M., Rao, P.V.V.P., Rao, S.S., 2019. Impact assessment of India's Swachh Bharat Mission – clean India campaign on acute diarrheal disease outbreaks: yes, there is a positive change. J. Fam. Med. Prim. Care 8 (3), 1202–1208. https://doi.org/10.4103/jfmpc.jfmpc_144_19.

Davis, A., Javernick-Will, A., Cook, S.M., 2019. The use of qualitative comparative analysis to identify pathways to successful and failed sanitation systems. Sci. Tot. Environ. 663, 507–517.

Dillon, P., 2015. Australian progress in managed aquifer recharge and the water banking frontier. AWA Journal Water 42, 53–57.

Dillon, P., Vanderzalm, J., Sidhu, J., Page, D., Chadha, D., 2014. A water quality guide to managed aquifer recharge in India. CSIRO and UNESCO https://doi.org/10.4225/08/584ee831925bb.

Dillon, P., Stuyfzand, P., Grischek, T., Lluria, M., Pyne, R.D.G., Jain, R.C., Bear, J., Schwarz, J., Wang, W., Fernandez, E., Stefan, C., Pettenati, M., van der Gun, J., Sprenger, C., Massmann, G., Scanlon, B.R., Xanke, J., Jokela, P., Zheng, Y., Rossett, R., Shamrukh, M., Pavelic, P., Murray, E., Ross, A., Bonilla Valverde, J.P., Palma Nava, A., Ansems, N., Posavec, K., Ha, K., Martin, R., Sapiano, M., 2019. Sixty years of global progress in managed aquifer recharge. Hydrogeol. J. 27 (1), 1–30. https://doi.org/10.1007/s10040-018-1841-z.

Dillon, P., Page, D., Vanderzalm, J., Toze, S., Simmons, C., Hose, G., Martin, R., Johnston, K., Higginson, S., Morris, S., 2020. Lessons from 10 years of experience with Australia's risk-based guidelines for managed aquifer recharge. Water 12 (2), 537. https://doi.org/10.3390/w12020537.

Dorji, U., Tenzin, U.M., Dorji, P., Wangchuk, U., Tshering, G., Dorji, C., Shon, H., Nyarko, K.B., Phuntsho, S., 2019. Wastewater management in urban Bhutan: assessing the current practices and challenges. Process. Saf. Environ. Prot. 132, 82–93. https://doi.org/10.1016/j.psep.2019.09.023.

Drechsel, P., Keraita, B., 2014. Irrigated Urban Vegetable Production in Ghana: Characteristics, Benefits and Risk Mitigation. 2nd ed. International Water Management Institute (IWMI), Colombo, Sri Lanka 247 pp. http://www.iwmi.cgiar.org/Publications/Books/PDF/irrigated_urban_vegetable_production_in_ghana.pdf.

Drechsel, P., Seidu, R., 2011. Cost-effectiveness of options for reducing health risks in areas where food crops are irrigated with wastewater. Water Int. 36 (4), 535–548. https://doi.org/10.1080/02508060.2011.594549.

Drechsel, P., Graefe, S., Fink, M., 2007. Rural-urban food, nutrient and virtual water flows in selected West African cities. International Water Management Institute, Colombo, Sri Lanka, p. 35. https://doi.org/10.3910/2009.115 (IWMI Research Report Series 115).

Drechsel, P., Scott, C.A., Raschid-Sally, L., Redwood, M., Bahri, A. (Eds.), 2010. Wastewater Irrigation and Health: Assessing and Mitigation Risks in Low-Income Countries. Earthscan-IDRC-IWMI, UK, London (404 pp).

Eales, K., Blackett, I., Siregar, R., Febriani, E., 2013. Review of Community-Managed Decentralized Wastewater Treatment Systems in Indonesia. World Bank https://openknowledge.worldbank.org/handle/10986/17751.

Elangovan, N.S., Lavanya, V., Arunthathi, S., 2018. Assessment of groundwater contamination in a suburban area of Chennai, Tamil Nadu, India. Environ. Dev. Sustain. 20 (6), 2609–2621. https://doi.org/10.1007/s10668-017-0007-9.

Ensink, J.H.J., van der Hoek, W., Mara, D.D., Cairncross, S., 2007. Waste stabilization pond performance in Pakistan and its implications for wastewater use in agriculture. Urban Water J. 4 (4), 261–267. https://doi.org/10.1080/15730620701427429.

FAO, WHO, 2019. Safety and Quality of Water Used in Food Production and Processing – Meeting Report. Microbiological Risk Assessment Series No. 33 Rome.

Flörke, M., Schneider, C., McDonald, R.I., 2018. Water competition between cities and agriculture driven by climate change and urban growth. Nat Sustain 1 (1), 51–58. https://doi.org/10.1038/s41893-017-0006-8.

Ganguly, N., 2019. Slums of India. MJP Publishers (214 pp).

Garrick, D., De Stefano, L., Yu, W., Jorgensen, I., O'Donnell, E., Turley, L., Aguilar-Barajas, I., Dai, X., de Souza Leão, R., Punjabi, B., Schreiner, B., 2019. Rural water for thirsty cities: a systematic review of water reallocation from rural to urban regions. Environ. Res. Lett. 14, 043003. https://doi.org/10.1088/1748-9326/ab0db7.

GOI, 2011. Census of India 2011. Government of India, New Delhi, India.

Grönwall, J.T., Mulenga, M., McGranahan, G., 2010. Groundwater, Self-Supply and Poor Urban Dwellers: A Review with Case Studies of Bangalore and Lusaka. IIED.

GWI, 2014. Global Water Intelligence. Global Water Market 2014. Volume 1. Introduction and the Americas. Media Analytics Ltd, Oxford, UK.

Hamlyn-Harris, D., McAlister, T., Dillon, P., 2019. Chapter 9 – Water harvesting potential of WSUD approaches. In: Sharma, et al. (Eds.), Approaches to Water Sensitive Urban Design. Potential, Design, Ecological Health, Urban Greening, Economics, Policies, and Community Perceptions. Elsevier. https://doi.org/10.1016/B978-0-12-812843-5.01001-7.

Hoekstra, A.Y., Mekonnen, M.M., 2012. The water footprint of humanity. PNAS 109 (9), 3232–3237. https://doi.org/10.1073/pnas.1109936109.

Jaladhi, V., Dhruv, B., Utkarsha, K., Mahroof, M., 2016. Online performance assessment system for urban water supply and sanitation services in India. Aquatic Procedia 6, 51–63.

Jamwal, P., Lele, S., 2017. Addressing pollution in urban Rivers: What we learnt from the Vrishabhavathy River in Bengaluru. In: Hiremath, et al. (Eds.), Transcending Boundaries: Reflecting on Twenty Years of Action and Research at ATREE. ATREE, Bangalore, pp. 104–113.

Jiménez, B., Asano, T., 2008. Water Reuse: An International Survey of Current Practice, Issues and Needs. IWA Publishing, London.

Karg, H., Drechsel, P., 2011. Motivating behaviour change to reduce pathogenic risk where unsafe water is used for irrigation. Water Int. 36 (4), 476–490. https://doi.org/10.1080/02508060.2011.594684.

Keraita, B., Drechsel, P., 2015. Consumer Perceptions of Fruit and Vegetable Quality: Certification and Other Options for Safeguarding Public Health in West Africa. International Water Management Institute (IWMI), Colombo, Sri Lanka https://doi.org/10.5337/2015.215 32p. (IWMI Working Paper 164).

Kotter, T. 2004. Risks and opportunities of urbanisation and megacities. In: FIG (Hrsg.): The Olympic Spirit of Surveying, Proceedings of the FIG Working Week 22–27 May 2004 in Athens. https://www.fig.net/resources/proceedings/fig_proceedings/athens/papers/ps02/ps02_2_kotter.pdf (last accessed 16 Dec 2019).

Lazarova, V., Asano, T., Bahri, A., Anderson, J., 2013. Milestones in Water Reuse: The Best Success Stories. IWA (408 pp).

Lindsay, J., Dean, A.J., Supski, S., 2017. Responding to the millennium drought: comparing domestic water cultures in three Australian cities. Reg. Environ. Chang. 17, 565–577. https://doi.org/10.1007/s10113-016-1048-6.

Lumagbas, L.B., Coleman, H.L.S., Bunders, J., Pariente, A., Belonje, A., Buning, T. de C., 2018. Non-communicable diseases in Indian slums: re-framing the social determinants of health. Glob. Health Action 11 (1), 1438840. https://doi.org/10.1080/16549716.2018.1438840.

Lydecker, M., Drechsel, P., 2010. Urban agriculture and sanitation services in Accra, Ghana: the overlooked contribution. Int. J. Agric. Sustain. 8 (1–2), 94–103. https://doi.org/10.3763/ijas.2009.0453.

Macdonald, R.I., Weber, K., Podowski, J., Florke, M., et al., 2014. Water on an urban planet: urbanization and the reach of urban water infrastructure. Glob. Environ. Chang. 27, 96–105. https://doi.org/10.1016/j.gloenvcha.2014.04.022.

Maheshwari, B., Varua, M., Ward, J., Packham, R., Chinnasamy, P., Dashor, Y., Dave, S., Soni, P., Dillon, P., Purohit, R., Hakimuddin, Shah, T., Oza, S., Sing, P., Prathapar, S., Patel, A., Jadeja, Y., Thaker, B., Kookana, R., Grewal, H., Yadav, K., Mittal, H., Chew, M., Rao, P., 2014. Participation in village scale groundwater management: insights from Gujurat and Rajasthan, India. Water 6, 3386–3408. https://doi.org/10.3390/w6113386.

Maliva, R.G, 2019. Anthropogenic Aquifer Recharge. WSP Methods in Water Resources Evaluation Series No. 5. Springer, Cham (Switzerland).

McArthur, J.M., Sikdar, P.K., Hoque, M.A., Ghosal, U., 2012. Waste-water impacts on groundwater: cl/Br ratios and implications for arsenic pollution of groundwater in the Bengal Basin and Red River Basin, Vietnam. Sci. Total Environ. 437, 390–402. https://doi.org/10.1016/j.scitotenv.2012.07.068.

Mekonnen, M.M., Hoekstra, A.Y., 2016. Four billion people facing severe water scarcity. Sci. Adv. 2 (2). https://doi.org/10.1126/sciadv.1500323.

Molle, F., Berkoff, J., 2006. Cities Versus Agriculture: Revisiting Intersectoral Water Transfers, Potential Gains and Conflicts. Comprehensive Assessment Research Report 10. Colombo, IWMI.

MoUD, 2017. National Policy on Faecal Sludge and Septage Management (FSSM). Government of India Ministry of Urban Development, New Delhi, India http://amrut.gov.in/upload/newsrelease/5a5dc55188eb0FSSM_Policy_Report_23Feb.pdf.

Murray, A., Drechsel, P., 2011. Why do some wastewater treatment facilities work when the majority fail? Case study from the sanitation sector in Ghana. Waterlines 30 (2), 135–149. https://doi.org/10.3362/1756-3488.2011.015.

Muyen, Z., Moore, G.A., Wrigley, R.J., 2011. Soil salinity and sodicity effects of wastewater irrigation in south East Australia. Agri. Wat. Manag. 99 (1), 33–41. https://doi.org/10.1016/j.agwat.2011.07.021.

NITI Aayog, 2019. Composite Water Management Index. August 2019. National Institute for Transforming India http://niti.gov.in/sites/default/files/2019-08/CWMI-2.0-latest.pdf.

Nitivattananon, V., Srinonil, S., 2019. Enhancing coastal areas governance for sustainable tourism in the context of urbanization and climate change in eastern Thailand. Adv Climate Change Res 10 (1), 47–58. https://doi.org/10.1016/j.accre.2019.03.003.

NRMMC-EPHC-AHMC, 2006. Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1). Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, Australian Health Ministers' Conference, Canberra.

NRMMC-EPHC-NHMRC, 2009. Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2): Managed Aquifer Recharge. Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, National Health and Medical Research Council, Canberra.

Onodera, S., Saito, M., Sawano, M., et al., 2008. Effects of intensive urbanization on the intrusion of shallow groundwater into deep groundwater: examples from Bangkok and Jakarta. Sci. Tot. Environ. 404 (2–3), 401–410. https://doi.org/10.1016/j.scitotenv.2008.08.003.

Otoo, M., Drechsel, P. (Eds.), 2018. Resource Recovery from Waste: Business Models for Energy, Nutrient and Water Reuse in Low- and Middle-Income Countries. Routledge, London (816 p).

Prakash, K.L., Somashekar, R.K., 2006. Groundwater quality assessment of Anekal taluk, Bangalore urban district. Indian J. Environ. Biol. 27 (4), 633–637.

Qadir, M., Wichelns, D., Raschid-Sally, L., McCornick, Peter G., Drechsel, P., Bahri, A., Minhas, P.S., 2010. The challenges of wastewater irrigation in developing countries. Agric. Water Manag. 97 (4), 561–568. https://doi.org/10.1016/j.agwat.2008.11.004.

Ramesh, A., Nagendra Prakash, B.S., Sivapullaiaih, P.V., Sadhashivaiah, A.S., 2012. Assessment of groundwater quality in designated Peenya industrial area and estate, Bengaluru, India-a case study. Int. J. Environ. Prot. 2 (6), 21–25.

Rao, K.C., Kvarnström, E., Di Mario, L., Drechsel, P., 2016. Business Models for Fecal Sludge Management. Resource Recovery and Reuse Series 6. IWMI. CGIAR Research Program on Water, Land and Ecosystems (WLE), Colombo, Sri Lanka (80 pp).

Saldias, C.Z., 2016. Analyzing the Institutional Challenges for the Agricultural (Re)Use of Wastewater in Developing Countries. PhD Dissertation. University of Ghent (263 pp).

Satapathy, B.K., 2014. Safe drinking water in slums. From water coverage to Water Quality Economic & Political Weekly June 14, 2014 Vol XLIX no 24. http://www.indiaenvironmentportal.org.in/files/file/Drinking%20Water%20in%20Slums.pdf.

Sato, T., Qadir, M., Yamamoto, S., Endo, T., Zahoor, A., 2013. Global, regional, and country level need for data on wastewater generation, treatment and use. Agr. Water Manage. 130, 1–13. https://doi.org/10.1016/j.agwat.2013.08.007.

Sengupta, S. 2018. At least 200 cities are fast running out of water. Down to earth (India). https://www.downtoearth.org.in/news/water/bengaluru-beijing-mexico-city-and-istanbul-are-some-of-the-cities-that-are-headed-towards-day-zero-59984 (last accessed 16 Dec 2019).

Sharma, A.K., Gardern, T., Begbie, D., 2018. Approaches to Water Sensitive Urban Design. Potential, Design, Ecological Health, Urban Greening, Economics, Policies, and Community Perceptions. Elsevier Inc.

Shi, L., Kone, D., et al., 2010. A Rapid Assessment of Septage Management in Asia: Policies and Practices in India, Indonesia, Malaysia, the Philippines, Sri Lanka, Thailand, and Vietnam. USAID, AECOM International Development and Swiss Federal Institute of Aquatic Science and Technology.

Silva, M.M.V.G., Gomes, E.M.C., Isaias, M., Azevedo, J.M.M., Zeferino, B., 2017. Spatial and seasonal variations of surface and groundwater quality in a fast-growing city: Lubanga, Angola. Environ. Earth Sci. 76 (23), 790. https://doi.org/10.1007/s12665-017-7149-9.

Sinha, M., Khan, M.A., 2001. Impact of environmental aberrations on fisheries of the Ganga (Ganges) River. Aquat. Ecosyst. Health Manag. 4 (4), 493–504. https://doi.org/10.1080/146349801317276143.

Thebo, A.L., Drechsel, Pay, Lambin, E.F., 2014. Global assessment of urban and peri-urban agriculture: irrigated and rainfed croplands. Environmental Research Letters Environ. Res. Letters 9 (2014), 114002. http://iopscience.iop.org/1748-9326/9/11/114002/pdf/1748-9326_9_11_114002.pdf.
Thebo, A.L., Drechsel, P., Lambin, E.F., Nelson, K.L., 2017. A global, spatially-explicit assessment of irrigated croplands influenced by urban wastewater flows. Environ. Res. Lett. 12 (7), 074008. https://doi.org/10.1088/1748-9326/aa75d1.
Tidwell, J.B., Chipungu, J., Bosomprah, S., Aunger, R., Curtis, V., Chilengi, R., 2019. Effect of behaviour change intervention on the quality of peri-urban sanitation in Lusaka, Zambia: a randomised controlled trial. The Lancet Planetary Health 3, e187–e196.
Trommsdorf, C., 2020. Nature for cities or cities for nature? Blog March 6, 2020. International Water Association (last accessed on 7th May 2020). https://iwa-network.org/nature-for-cities-or-cities-for-nature/.
UN 2017. Habitat III- New Urban Agenda. http://habitat3.org/ (last accessed 16 Dec 2019).
UN DESA (2018). World urbanisation prospects 2018. UN Department of economic and social affairs: population dynamics. https://population.un.org/wup/ (last accessed 16 Dec 2019).
UN SDG-6 2018. Sustainable development goal 6: synthesis report 2018 on water and sanitation. https://www.unglobalcompact.org/library/5623 (last accessed 16th Dec 2019).
UNESCO, 2016. Water, Megacities and Global Change. Portraits of the 15 Emblematic Cities of the World. UNESCO, Paris (France).
USAID, 2010. A Rapid Assessment of Septage Management in Asia: Policies and Practices in India, Indonesia, Malaysia, the Philippines, Sri Lanka, Thailand, and Vietnam. A Report by AECOM International Development, Inc. and the Department of Water and Sanitation in Developing Countries (Sandec) at the Swiss Federal Institute of Aquatic Science and Technology (Eawag) for US Agency for International Development (USAID).
Valipour, M., Singh, V.P., 2016. Global experiences on wastewater irrigation: challenges and prospects. In: Maheshwari, B., Singh, V.P., Thoradeniya, B. (Eds.), Balanced Urban Development: Options and Strategies for Liveable Cities. Springer International Publishing, Cham, pp. 289–327.
Van Veenhuizen, R., Danso, G., 2007. Profitability and Sustainability of Urban and Peri-Urban Agriculture. FAO Agricultural Management, Marketing and Finance Occasional Paper no 19. FAO, Rome.
Vanderzalm, J., Cox, J., Oliver, D., Mallants, D., Phogat, V., van Leeuwen, J., Awad, J., Pezzaniti, D., Hatch, M., Batelaan, O., Pitt, T., 2019. Sustainable Expansion of Irrigated Agriculture and Horticulture in Northern Adelaide Corridor. Task 5: Summary Report. Goyder Institute for Water Research Technical Report Series no. 19/18.
Vanham, D., Hoekstra, A.Y., Wada, Y., et al., 2018. Physical water scarcity metrics for monitoring progress towards SDG target 6.4: an evaluation of indicator 6.4.2 "level of water stress". Sci Tot Environ 613–614, 218–232. https://doi.org/10.1016/j.scitotenv.2017.09.056.
Varadhan, S., 2019. RPT-villagers accuse city of seizing water as drought parches "India's Detroit". https://fr.reuters.com/article/idAFL4N2432SZ.
Vidal, J. 2018. The 100 million city: is 21st century urbanisation out of control? The Guardian. https://www.theguardian.com/cities/2018/mar/19/urban-explosion-kinshasa-el-alto-growth-mexico-city-bangalore-lagos (last accessed 16 Dec 2019).
Vijay, R., Khobragade, P., Mohapatra, P.K., 2010. Assessment of groundwater quality in Puri City, India: an impact of anthropogenic activities. Environ. Monit. Assess. 177 (1–4), 409–418. https://doi.org/10.1007/s10661-010-1643-9.
WB, 2019. The World Bank. Urban Development: Overview. https://www.worldbank.org/en/topic/urbandevelopment/overview (Last accessed 13 Jan 2020).
WHO, 2006. Guidelines for the safe use of wastewater, excreta and greywater. Wastewater Use in Agriculture. Volume 2. World Health Organization, France.
Willetts, J., Wicken, J., Robinson, A., 2008. Meeting the sanitation and water challenge in south-East Asia and the Pacific. Synthesis Report on the AusAID Sanitation and Water Conference.
World Bank/Water and Sanitation Program (WSP), International Water Management Institute (IWMI), 2016. Recycling and Reuse of Treated Wastewater in Urban India: A Proposed Advisory and Guidance Document. IWMI, Colombo, Sri Lanka (CGIAR Research Program on Water, Land and Ecosystems (WLE). 57p. (Resource Recovery and Reuse Series 8).
WWAP, 2017. The United Nations World Water Development Report 2017: Wastewater, the Untapped Resource. UNESCO, Paris (France).
Yazdi, P., 2011. A survey on social issues in replacing effluent with agricultural water rights (Case Study: Replacing Mashhad Effluent with water rights from Karder River). International Congress on Irrigation and Drainage, 15–23 October, Tehran, Iran.
Yeboah-Agyepong, M., Amoah, P., Agbo, W.N., Muspratt, A., Aikins, S., 2019. Safety assessment on microbial and heavy metal concentration in Clarias gariepinus (African catfish) cultured in treated wastewater pond in Kumasi, Ghana. Environ. Technol. 40 (3), 302–311. https://doi.org/10.1080/09593330.2017.1388851.