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Sustainable and Resilient Water and Energy Futures: From New Ethics and Choices to Urban Nexus Strategies

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Additional information is available at the end of the chapter

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Abstract

A safe, secure and affordable water future—for life, health, economy—are foundational outcomes from a new form of ethics for water stewardship and energy management. Current business as usual in water and energy systems have not led to sustainable, healthy nor resilient pathways for urban and rural communities alike. Today, an estimated 400 million people live in cities with significant water shortages. This is while 25% of water is currently lost before even used in urban areas (up to 60% in some cities) due to aging infrastructure. In addition, on average, only 10% of wastewater is treated before returning to water bodies in developing countries. By 2040, more than 66% of the world's populations could suffer from severe water shortages; and by 2050, an 80% increase in urban water demand (over current levels) may result in one billion city dwellers and 36% (one in three) of cities expected to face water crises. A crisis is often a catalyst for innovation and this chapter is a call to cities to enable strategic responses—moving away from legacy 'siloes' infrastructures, over-allocated water resources and emerging ethical dilemmas to integrated water- and energy-related urban nexus strategies.

Keywords: ethics, choices, infrastructure, nexus strategies, resilient urban systems

1. Introduction

The world's aquifers are being depleted at rapid rates due to growing populations and unsustainable urbanization practices, including land use sprawl and ever-increasing water and energy resource demands. According to recent analyses, an estimated 400 million people already live in cities with significant water shortages today, and with an 80% increase in

urban water demand (over today's levels) projected by 2050, 1 billion city dwellers and 36% of (one in three) cities are expected to face water crises by 2050 [1]. Even earlier, by 2040, more than 66% of the world's populations could suffer from severe water shortage—all while 25% of water is lost before even used in urban areas (up to 60% in some cities), due to poor maintenance or infrastructure. In addition, on average, only 10% of wastewater is treated before returning to water bodies in developing countries [2].

Current lack of reliable infrastructure, high levels of pollution, increasing frequency and intensity of extreme weather events (e.g. droughts, flooding, wildfires), power outages for water and wastewater utility services in and around cities—all these factors will continue to affect reliable water supply, quality of services, and health—from Flint, Michigan; Cape Town, South Africa; to Delhi, India. This does not bode well for cities lacking long term strategies that respond to challenges of rising water demands for urban, agricultural, energy, and industrial production systems; and new global risks.

Ethical dilemmas and painful choices are emerging from 'lock-in' effects and environmental change to outdated governance and institutional regulatory/decision structures that have been driven by siloed systems decisions and unsustainable approaches to consistently delivering basic water, energy, food, and waste management services in an increasingly urban world. Aging infrastructure, increasingly over-allocated water resources and lack of strategies to mitigate risks (associated with urbanization, economic and environmental stress, and cybersecurity) have, in many parts of the world, brought ethical dilemmas to the forefront. In fact, this chapter outlines how many global cities are still relying on nineteenth century water policies and twentieth century infrastructure yet are now confronted with paralyzing twenty-first century challenges. In general, there is a 'rear-view mirror' approach and urban water management—continuing to look to the past to guide infrastructure planning and public policy (e.g. the loss of stationarity in water planning) with limited funds to modernize services.

2. From pain points and ethics dilemmas to urban solutions

Case studies that highlight and quantify critical pain points, narrate emerging ethical dilemmas, and outline breakthrough, interdisciplinary responses will be needed to enable new opportunities for improving quality of life, prosperity, sustainability and resilience of communities and cities. There are many examples of inaction or reaction to stresses and shocks in the urban water sector. They include current crises in water availability and quality issues in cities from Los Angeles, California to Flint, Michigan in the United States; to Sao Paulo, Brazil; Cape Town, South Africa; and Sana'a, Yemen globally; as well as increasing frequency and intensity of weather extremes and natural disasters (e.g. floods experienced in San Juan, Puerto Rico; to extreme heat in Lahore, Pakistan; to population migration in Beirut, Lebanon due to water-driven security risks in Syria; to persistent and water-related food insecurity in Addis Ababa, Ethiopia; to limited drinking water in Gaza and significant wastewater effluent discharges into the Mediterranean, increasingly leading to events of shutting down of Ashkelon's desalination plant, that now supplies up to 20% of Israel's drinking water) [6].

In this chapter, we define a spectrum of failures in current 'rear-view mirror' approaches to urban water strategy and their consequences. This is followed by the development of a preliminary urban response maturity model, in the next chapter, that's based upon learnings from recent water crisis events and other sectors (e.g., telecommunications to energy) which are also undergoing transformational change. For example, Bangladesh moving from almost zero mobile cellular subscriptions per 100 people in 2000 to over 78.8 per 100 people in 2015. In addition, solar PV prices declined almost 75% from 2010 to 2017 and onshore wind electricity by 25% to \$0.06USD/kWh in 2017.

Transformational changes often come from defining vectors forward toward 'leapfrogs' in technologies decision systems and systems integration processes that move from reactive crisis response-modes, voluntary programs, and inadequate data systems to proactively accepting responsibility for informed market-enabling technologies, that could spur many new shared economy or water and energy development models—especially focused on rapidly urbanizing areas. A focus on integrated, ethics, and performance-based urban nexus strategies is defined as follows:

Urban NEXUS strategies (UNS) will refer in this chapter to an emerging approach and process that aims to integrate actors, knowledge, data, and assessment tools to inform the design of best practices that can be leveraged and shared across sectors and domains to deliver sustainable, healthy, and resilient water and energy systems and infrastructure services that improve quality of life while catalyzing urban innovation.

While the majority of this chapter explores the complex urban water challenges and responses needed ahead, an aspiration of 'leapfrogs' forward via urban nexus strategies are anticipated to help target more ambitious goals and integrated metrics for risk mitigation, to enhance a city's global competitiveness—in a rapidly evolving market place for innovative solutions to urban water crises. Trends of on-demand, data-driven analytics informing integrated, or nexus (rather than siloed)-based governance of critical resource-based services may also bring forward new ethics-driven decision and behavioral approaches as a key component to systems integration for UNS.

3. Water stressed cities and urban water-energy nexus responses

Throughout history, civilizations and cities have primarily located where water is plentiful—along coastlines, rivers, lakes, and mountains. Cities without water are a catalyst for many forms of instability—from economic and social to environmental, agricultural and political. This is an increasing challenge for many of the world's megacities, as well as smaller to mid-size cities that are urbanizing and industrializing at a rate of change that's been unparalleled in history. Between 2000 and 2025, it is expected that the number of megacities will roughly double, and with urban populations of 1 million reaching 2 million in timeframes as short as 8–12 years. This has significant implications for abilities to keep up with growth and maintain sustainable water services (**Figure 1**).

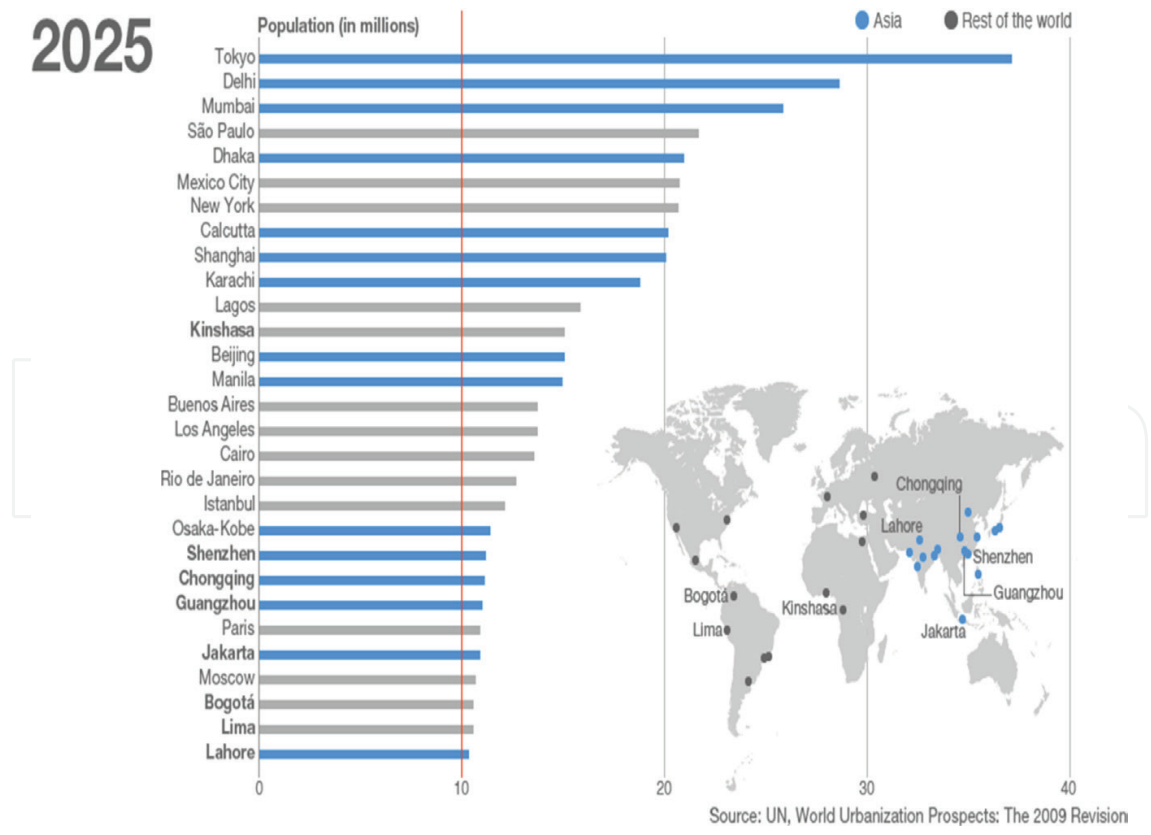
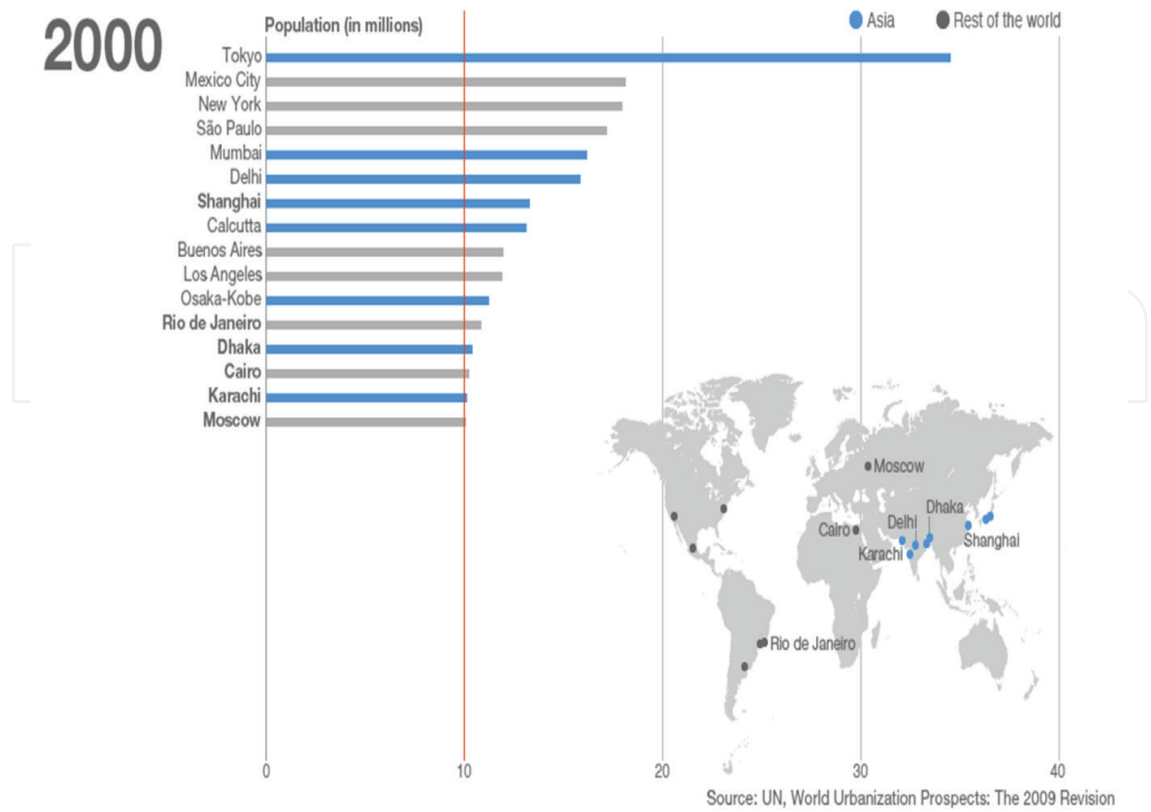


Figure 1. Mega-cities in 2000 vs. 2025 (note: today megacities represent 10% of world urban population, with smaller to mid-size cities often having more limited resources to adapt to change) [3].

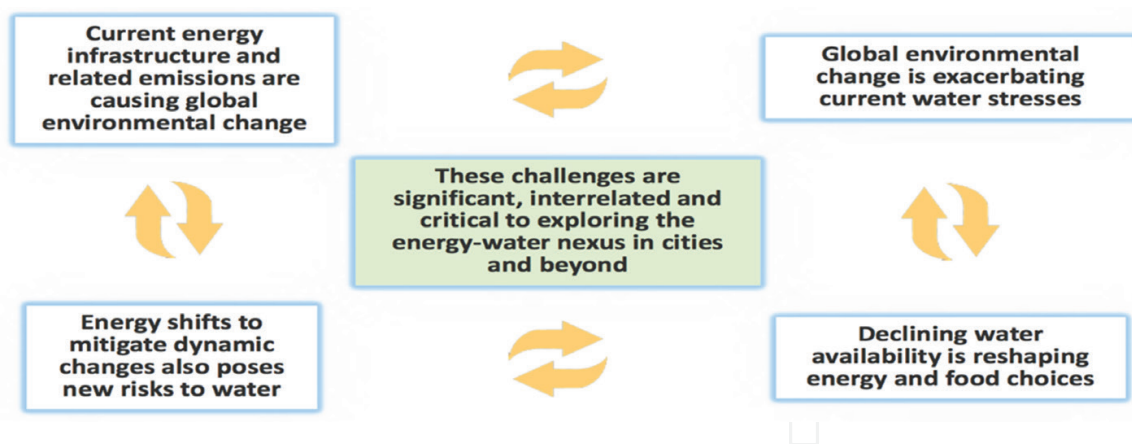


Figure 2. Interdependencies of the energy water food nexus.

Cities in wet to dry geographies are now facing increasing population and resultant resource demands. They are also in a unique position to transform water, energy and food nexus stress into strategies to vastly improve resilience and create abundance. An integrated strategy to manage nexus stress is needed for cities to thrive, economically and socially, in the twenty-first century. **Figure 2** illustrates the interactions and interdependencies of these trends and key urban resilience challenges.

4. Urban water data: understanding risks

The CDP Water program has developed research on the responses of global cities to these risks. The research indicates the cities most concerned about their water supply are in Asia and Oceania (84%), with serious risks also identified in Africa (80%) and Latin America (75%). Sixty-three percent of North American cities consider climate change a risk to water supply, with fewer cities concerned in Europe (34%). One hundred and ninety-six cities reported risks of water stress and scarcity, 132 a risk of declining water quality and 103 a risk of flooding.

CDP's new infographic report 'Who's Tackling Urban Water Challenges', produced in partnership with AECOM, the global infrastructure firm, and funded by Bloomberg Philanthropies, offers a first dataset of global water action by cities and companies. Using information gathered from 569 cities and 1432 companies, each reporting their water management activity, the database illustrates how global cities and companies are responding to the escalating challenge of resource constraints, rising demands, and changing conditions.

Businesses are also reporting to CDP on impacts from water scarcity and flooding. In 2017, 535 companies (70%) have board level oversight of water issues and are reaping the rewards, including market differentiation, shareholder confidence and business resilience. In 2017, companies committed US\$23.4 billion across more than 1000 projects to tackle water risks across 91 countries worldwide, including desalination, reclaiming waste-water and improving irrigation to avoid droughts [4].

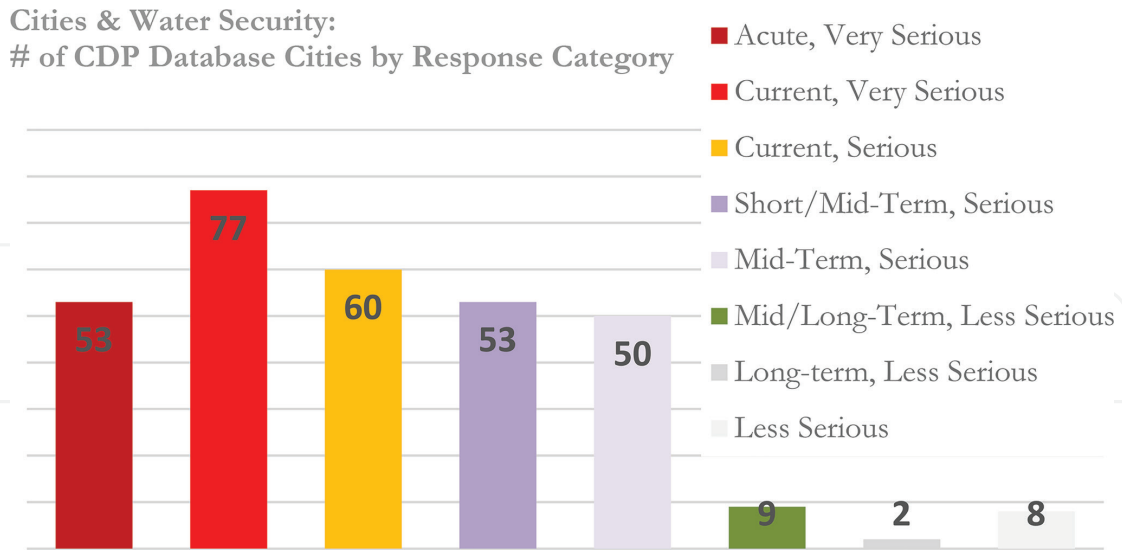


Figure 3. Urban risk timescales, magnitude, CDP cities water security database [5] (n = 312 cities; self-reported).

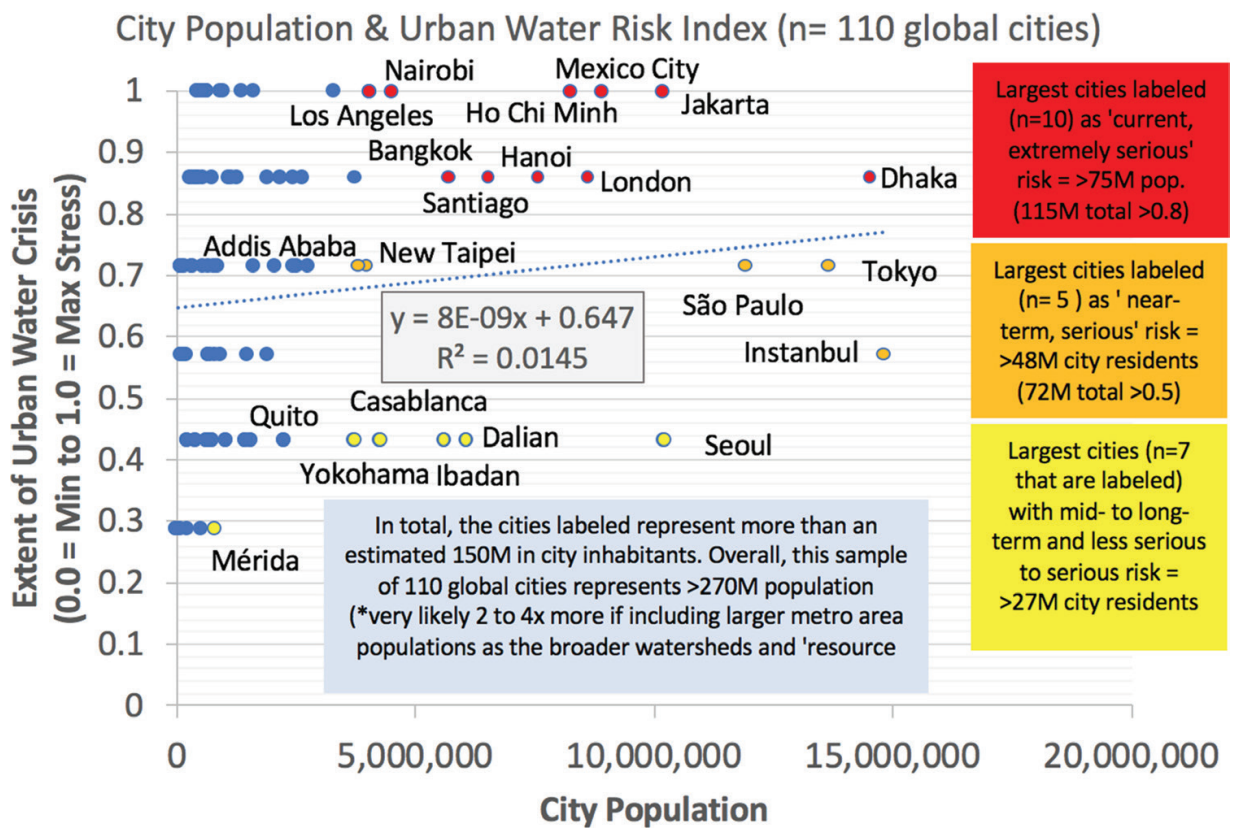


Figure 4. One hundred and ten global cities that are categorized into lower, medium and higher water risk categories. Re-analysis of September 2017 data from CDP [5].

Data re-analyses of the CDP Cities and Water Security self-reported database are shown in **Figure 3**. This includes exploring data from 312 cities in terms of water insecurity risk type, level of severity and the temporal nature of these risks (keeping in mind a need to balance the biases that may be associated with self-reported data). This is followed by a greater emphasis

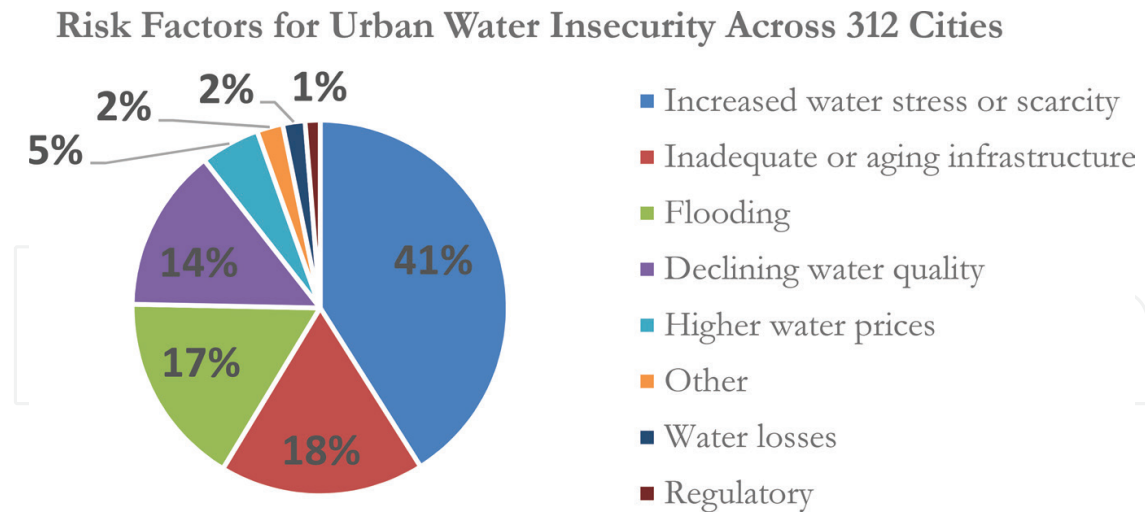


Figure 5. Proportional assessment of types of risks shaping water insecurity [5].

in next section on solutions, decision systems, and maturity levels—to operationalize the framework—on urban water strategy maturity, focusing on systems integration and service innovation across sectors and ‘siloes’ (Figures 4 and 5).

5. Exploring risk descriptions from ‘hotspot’ cities

An overview of impacts in the cities with some of the highest risk of water insecurity are provided below.

Jakarta

- Scarcity of clean water, especially in areas near the coast of North Jakarta and West Jakarta
- Pollution caused by industrial and household activities
- Increased frequency of rain affecting the area, with increased inundation/flood areas

Karachi

- Water riots expected as 1 Billion gallon per day requirement is only met with 600 Mgd

Nairobi

- Currently, the output of all the water sources for the city is 570,000 cubic meters against a demand of 740,000 cubic meters. This means we only meet 77% of current water demand.
- The current reticulation infrastructure is very old and, as a result, contributes to huge water losses due to leakages.
- With the flooding associated with the heavy downpours that the city experiences, there have been instances where water pipes have been swept away.

Moscow

- Risk of release of hazardous polluting substances, leading to failure of technological modes of sewerage networks and sewage treatment plants.
- Risk of accidents on sewerage networks, pumping stations and wastewater treatment plants in connection with wear and insufficient volume of measures for their renovation, as well as in connection with failure of external power supply.
- Risk of accidental pollution of water sources, existing due to anthropogenic pressures, leading in particular to deterioration of water quality, primarily on organoleptic and microbiological indicators, the content of organic substances and petroleum products.
- Mass development of cottages development in water-collecting area and discharge of untreated waste water lead to gradual degradation of small rivers, deterioration of self-purification capacities of water bodies, and algal blooms. Deterioration of water supply systems also affects the quality of the water supplied to consumers.

Cape Town

- The city has generally been able to successfully manage and reduce demand growth; however, Cape Town is currently suffering from a drought lasting several years (currently in year 3) which has severely impacted the City's water storage.
- Stringent level 3b water restrictions have been put in place to reduce demand further. It is anticipated that in the longer term, water demand will continue to grow and place stress on the supply system.
- The city is currently conducting cooperative planning with the national Department of Water and Sanitation to ensure that additional water supply infrastructure is constructed to avoid a long-term water deficit in the region. Climate change is expected to change rainfall patterns, and this has been included as a scenario in the planning for future infrastructure. Climate change is expected to reduce rainfall, increase evaporation and increase demand due to increased temperature.

Mazabuka

- Inadequate rainfall results in droughts, damaged crops, declining wildlife and deaths
- Hydroelectricity issues, for instance—no electricity in homes at certain intervals due to road shading and you only see power for only 2 hours.
- People consuming contaminated water, due to dried and stagnant water sources, leads to water borne diseases.

Mexico City

- The city has identified and mapped flooding impacts for vulnerable areas—targeting 5.6 million inhabitants.

- So far there are over 41.1% leaks in the water system. There is constant pressure on the aquifer and the 2040 water plan has identified this as the highest level of risk.

Lagos

- Wastewater treatment plants available are not sufficient to treat wastewater for the whole city
- Over abstraction of ground water from aquifers
- Mismanagement of water resources, such as leaking taps, lead to scarcity of water availability
- Reduction in quantity of water available for domestic, industrial and commercial use

Johannesburg

- A crippling drought that was associated with El Niño severely affected South Africa's summer rainfall in regions including Johannesburg.
- Dam levels were at critical low levels such that water restrictions had to be imposed and penalties on those who used excessive water.

Los Angeles

- Deferred maintenance on water system

Las Vegas

- As Lake Mead's level declines, concerns of declining water quality due to increased salinity.
- Recent third intake project at lowest part of lake to mitigate water quality concerns.
- Water restrictions; yet if Lake Mead continues to decline, a Federally mandated cut in Southern Nevada's water allocation may occur, and nearly did during 2015-2016.

6. Extent, consequences, and drivers of urban water crises

This section focuses on city and regional-decision making processes that will matter. Below offers example 'cities most likely to run out of drinking water', with some related trends, the potential consequences in these changing urban environments, and multi-level (e.g. city, state, national) responses. While data integration across systems may help to inform future risk communication, increased availability of data and a need for data integration and transparency requires new analytics coupled with decision processes, enabling a higher level of maturity in response levels that move from reactive to proactive. Several predictive factors are therefore noted from both data and literature-reviewed in these cities, offering contexts where scarcity may increase to insights on where 'abundance strategies' may prove of value (see Sarni and Sperling).

6.1. Sao Paulo (estimated metro region population: 21 million)

- *Indicators on extent of crisis:* During the 2014 water crisis, the city's main reservoir was at 3% capacity and the City had less than 20 days' water supply [7]. In the period of early twentieth century up to 2015, 12-month estimates of rainfall reached levels that were at half the amount of all previous worst 12-month periods [8].
- *Crisis consequences:* \$925 million of investment by water company, Sabesp, in three new water pumping projects to provide enough back-up water to survive a drought similar to the 2014–2015 event; many taps flowed for only a few hours every 4 days; theft and looting of emergency water trucks; 71% of city population experienced problems with the water supply during worst month, and with most acute impacts of going dry felt in the *Periferia*—poorer districts on the city; while wealthier residents built water tanks and purchased water from private sources, outlying cities saw large protests with some turning violent when city tried to cut off from water network entirely; dehydration of children, women with urinary problems from not drinking enough water, and significant business risks to factories and farm output; water shortages also impacted hydropower plants in the metro region forcing energy rationing (with principal hydropower reservoirs at 17% capacity)
- *Risk factors and Responses:* 10-fold increase in city population from 1950 to 2005 and uncontrolled urban expansion with informal settlements lacking adequate water services; pollution of rivers, deforestation in Amazon River basin and water-intensive agriculture; network leakages leading to 25% of produced water not reaching water users; main responses to date have included expensive, supply-side engineering / infrastructure investment to avoid future shortages rather than reducing consumption and leakage.

6.2. Bangalore (estimated metro region population: 11 million)

- *Indicators on extent of crisis:* City water distribution networks only cover the central area of the city, whereas surrounding areas are not connected and instead get their water supply from tanker trucks (typically relying on quickly shrinking groundwater supply that have dropped from depths of 150–200 ft. to 100 ft. or more in some places).
- *Crisis consequences:* Sept 2, 2016 Supreme Court issued-order for Karnataka to release extra water (10,000 cubic feet of water per second, then 15,000 from Sept 5 to 15 Sep and 12,000 until Sept 20) from the Cauvery river to ease a shortage threatening crops in Tamil Nadu; this led to violent/deadly protests in Bangalore forcing closures of hundreds of companies and public transit system (city police imposed an emergency law prohibiting public gatherings, with more than 15,000 officers deployed across the city).
- *Risk factors and Responses:* Total extraction wells from 5000 to 450,000 in the past 30 years; groundwater table drop from 10-12 meters to about 76–91 meters in just two decades with minimal groundwater recharge and rising water body pollution due to unplanned urbanization. The Bangalore Water Supply and Sewerage Board (BWSSB) is working with the Japanese International Cooperation Agency to divert 10 thousand million cubic feet of

water from the Cauvery River for drinking water (anticipated to provide ~100 L of water per person per day), gaining an additional 50% more than current supply. Other responses to date have included plans for an 18 month project to divert water from another river, the Netravati, as well as mandatory construction of rainwater harvesting facilities (collecting \$300,000 in fines per month from those not complying) and recycling water using sewage treatment plants [9, 10].

6.3. Beijing (estimated metro region population: 22 million)

- *Indicators on extent of crisis:* 100 cubic meters is available per person per year (note: less than 1000 cubic meters/capita annually is considered “water scarce” by UN standards). Price of water remains a quarter of the world’s average; 12 consecutive years of drought, noted in 2011, led to investments in desalination and piping from the Bohai sea [11].
- *Crisis consequences:* Three new routes for diverting water from south to north could cost more than \$80 billion with experts having doubts as to this being a long term sustainable solution (yet rather a ‘lifeline’ of water in the short term) [12]; 112 million regional population across Beijing/Tianjin/Hebei faces half of country’s acute scarcity, where 28,000 rivers have disappeared in past 25 years, groundwater is falling by up to 1–3 m a year, and some parts of Beijing subsiding by 11 cm a year. Yellow River water supplies millions, yet is now at a tenth of 1940 flow levels and often fails to reach the sea [13].
- *Risk factors and Responses:* In 2017, 8.8% of water was unfit even for agricultural or industrial use with pollution causing further risk to supply [13]; estimates of more than 50 million people in Beijing by 2050 [14]; groundwater decline and widespread water pollution; diverting water from Yangtze river in south; ‘sponge city’ pilots using up to 70% of rainfall; water recycling; drought resistant crops; Tianjin desalination infrastructure investments

6.4. Cairo (estimated metro region population: 19.5 million)

- *Indicators on extent of crisis:* Population growth (Egypt’s overall population is expected to double by 2050) and significant environmental pollution (especially chemically treated sewage disposal and industrial waste that’s killing crops) have led to the Nile river becoming the recipient of significant urban wastewater due to the lack of wastewater treatment plants in Cairo and rural agriculture and industrial runoff [15]. Below offer results from water samples at different water treatment plants in Cairo in the past decade [16]: cryptosporidium was found in 50% of samples taken from the Fowa drinking water treatment plant to 100% of samples in the El Nomros plant, and with Giardia as high as 33% in the El Hawamdia to 50% in Meet Fares. Over the past decade, the peri-urban areas, or outskirts of Cairo, have also been under significant development—this has included illegally constructed buildings linked to unauthorized use of primarily leaky water pipelines that then waste limited urban water supplies.

- *Crisis consequences:* Some have noted the Nile is now running out of clean water and with continued uneven water distribution, misuse of water resources, and inefficient irrigation techniques – 20 cubic meters per person of internal renewable freshwater resources has now become the norm nationwide. By 2020, Egypt will consume 20% more water than is available. This has meant an annual 7 billion cubic meters water deficit and UN predictions that the entire nation of Egypt could run out of water by the year 2025 [17]. In addition, due to groundwater uses for irrigation affecting the water table, structural integrity of several buildings and historic monuments in Cairo remain at risk as well.
- *Risk Factors and Responses:* Serious urban health hazards ranging from diarrhea, eye infections and rheumatism – associated with exposure to sewage – have been indicators of increasing risk since the late 1970s. This includes a high ranking for the number of deaths related to water pollution. In response, USAID alone has invested more than \$3.5 billion to improve water and sanitation services for over 25 million Egyptians (in a country just under 100 million today and expected to reach 200 million in next 50 years). More recently, in West Cairo, a \$727 million project was developed and implemented to improve wastewater collection, treatment, and disposal [18].

6.5. Jakarta (estimated metro region population: 30 million)

- *Indicators on Extent of Crisis:* Excessive groundwater water extraction over the last three decades has led the city to be one of the fastest sinking cities in the world and people are leaving [19]. Land subsidence is at a rate of 3 cm to 20 cm per year in parts of city (including 5 to 8 cm a year in the northern half of the city). Meanwhile, Jakarta's population has increased from ~8.3 million (2000) to 10,075 million (2015), without increases in environmental service (e.g. clean water provision, waste water treatment) capacities. Flooding occurs almost every time it rains more than three hours (with widespread flooding inundating up to 40% of the city in 1996, 2002 and 2007 [20]), only 50% of households have piped water (with new connections for low income households remaining very low – 85% of households that have connections fall into tariff categories of middle class or above [21], and the city now produces more wastewater than clean tap water. Finally, river water quality status in Jakarta has reached levels of 81% indicated as highly polluted in 2004 up to 94% in 2007, while green space in Jakarta's 1985–2005 to 2000–2010 spatial plans decreased from 26.1% to 13.94%.
- *Crisis Consequences:* Only 4% of housing in Jakarta has wastewater treatment plant connections. Jakarta has become a heavily polluted city in terms of sewage and water. This includes 70% of waterways being blocked, as a central driver of the city's chronic flooding problems. Twenty percent of daily waste still ends up in local rivers and canals, causing significant illness. Flooding has also led to the displacement of more than one million people, and billions of dollars in losses have ensued. In 2007 alone, nearly 70% of the city was submerged by floodwaters – 52 fatalities and displacement of more than 450,000 [22].
- *Risk Factors and Responses:* With support of international donors, and national government, the city administration started in 2016 to dredge its 17 rivers and canals for the first time since the 1970s. Other (somewhat inadequate) responses have included building of

shopping malls and apartment blocks as unchecked development, that would normally be retention ponds, swampland and other open spaces that would normally absorb rainwater.

6.6. Moscow (Est. 12 million)

- *Indicators on Extent of Crisis:* Insecure sources of water; water stress; water pollution- 56% of water supply sources fail to meet safety standards [23]
- *Crisis Consequences:* Health risks due to heavy metals, soil and groundwater contamination
- *Risk Factors and Responses:* Inadequate or aging infrastructure, declining water quality (CDP, 2017); and low incentives to take steps to improve quality of wastewater.

6.7. Istanbul (Est. 14 million)

- *Indicators of Extent of Crisis:* Distant from water sources; from 2006 to 2008, rainfall was lowest recorded in last 50 years; in 2014, another drought led to reservoirs dropping to as low as 29%; treatment plants are outdated; supply deficit (in million m³/year) was 473.2 in 2005 and 682.0 in 2010 [24]
- *Crisis Consequences:* Ongoing pollution to waterways; from drought to mega infrastructure projects of dams and canals; ecosystem impacts to nearby streams, water tables, large costs, and potential flooding anticipated with heavy rains.

Risk Factors and Responses: Increased water stress or scarcity (as serious medium-term risk); 2.8% annual growth rate (population doubling in 25-year period); Melen dam now expected to help Istanbul meet water demand until 2071, yet with higher water prices in long-term; and continued prolongation of dry season creating pressure on water resources (CDP, 2017).

The similarities among these examples are: 1) continued lack of data and metrics on water use and management; 2) lack of incentives or markets for solutions; 3) aging, centralized systems for infrastructure; 4) lack of business models for small, modular systems that may increase abundance and resilience; and 5) inadequate institutional mapping of roles to inform accountability/transparency in crisis response. These examples offer a diverse range of the sets of challenges, consequences, and emerging risks and responses. **Table 1** offers another summary of literature review approach, comparing Mexico City, London, Tokyo, and Miami, on recent crises related to resource quantity, quality, supply, demand, equity, and choices. These examples present a picture of the grand urban water challenges of the 21st century, with both differences and similarities between cities. Proactive strategies and integrated responses focused on the growing number of cities at risk as frontlines for innovation may continue to emerge. These examples also motivate questions for ongoing exploring of long-term impacts, using data to generate understanding on how best to help reduce costs, improve water security, modernize infrastructure assets, build resilience and ensure sustainable revenue models.

City	Resource quantity	Resource quality	Supply/demand challenges	Distributional & procedural equity	'Painful' choices and resilience priorities
Mexico City	Declining water resources; growing population; groundwater dependence limiting aquifer recharge	Poor water quality adaptations: increased purchasing of bottled water; plastic contributing to flood and drainage risks	Water scarcity; uncontrolled urban expansion; 30–40% of water supply lost to leaky systems & 1000s of informal taps	Water resources transferred over long distances, connecting city populations to resources in distant places; prioritization processes; ongoing flood risk	Investments in expensive water storage/supply-side water-management strategies reliance; new deep wells / water transfers from state of Veracruz; reuse strategies only recently emerging
London	London has a high level of leakage with around a quarter of London's water lost	Increased population/ heavy rainfall to further burden a drainage system that is in places already at capacity	Half of London's water mains pipe infrastructure is over 100 years old and a third is over a 150 years old	14,000 properties are at high risk (0.33% annual probability) of fluvial flooding and 140,000 properties are at high risk of surface water flooding	London flooding in 2000, 01, 03, 06, 07, 14 and 16. Infrastructure upgrading & reducing vulnerabilities to tidal, river, surface water, groundwater and sewer flooding
Tokyo	80% from Tonegawa & Arakawa River; 20% Tama River	Declining water quality	Increased water stress	Inadequate and aging infrastructure	Risks of flooding; investments in infrastructure and resource efficiency gains
Miami	Built on Biscayne aquifer	Contamination by seawater threatens quality of Miami water supplies	Increased water stress and scarcity	Water table overwhelming septic systems	Flooding risk and toxic chemicals on Superfund and other industrial sites into aquifer; 'desalination may one day be Miami's only option.'

Table 1. Comparisons of cities, megatrends, and resilience priorities.

7. Moving from grand challenges to critical nexus opportunities

New paradigms are emerging with water, energy, and related technologies identified as grand challenges. Innovation can create opportunities to both better leverage data and meet a global need for safe, secure and affordable water and through higher degrees of systems integration between water, energy, and 'X' systems (X is defined as a variable that may include food, land, waste resource recovery, environmental, economic, and urban systems – depending on local context priorities). Building on the National/Global Academies of Engineering twenty-first century grand challenges of 'restore and improve urban infrastructure', 'secure cyberspace', and 'provide access to clean water', this section of the chapter evaluates the critical opportunities to increase water, energy, environmental, social, economic, and security benefits, while significantly reducing costs, societal and business risks (e.g. supply chain vulnerabilities, conflict, economic outputs exposed and vulnerabilities to multiple hazards).

Given uncertainties associated with interrelated challenges, it's critical to not only define the grand water security challenge(s) for cities in the twenty-first century, yet further build up a more robust evidence base for integrated solutions. For purposes of defining urban community challenges in this chapter, we start with the fact that one in four of the world's 500 largest cities are already in a situation of "water stress" (ref, 2014) and that water crises, since 2011, have consistently been ranked in the top five of global risks in terms of impact (WEF Global Risks, 2018).

The economic consequences for inaction and holding on to old technology solutions are clear. The World Bank Report *High and Dry: Climate Change, Water and the Economy*, lays out a grim vision of inaction. Below are a few of the conclusions from the report:

- "Water scarcity, exacerbated by climate change, could cost some regions up to 6% of their GDP, spur migration, and spark conflict.
- The combined effects of growing populations, rising incomes, and expanding cities will see demand for water rising exponentially, while supply becomes more erratic and uncertain.
- Unless action is taken soon, water will become scarce in regions where it is currently abundant—such as Central Africa and East Asia— and scarcity will greatly worsen in regions where water is already in short supply—such as the Middle East and the Sahel in Africa. These regions could see their growth rates decline by as much as 6% of GDP by 2050 due to water-related impacts on agriculture, health, and incomes.
- Water insecurity could multiply the risk of conflict. Food price spikes caused by droughts can inflame latent conflicts and drive migration. Where economic growth is impacted by rainfall, episodes of droughts and floods have generated waves of migration and spikes in violence within countries."

The report also maps out the benefits of addressing the water crisis, such as improved economic development, and a call for action in improving agricultural water efficiency, better planning and investments in infrastructure to ensure more secure water supplies and availability. Most recently, a report released by NASA illustrates the impact of unsustainable pumping of aquifers. According to NASA, "The world's largest underground aquifers—a source of fresh water for hundreds of millions of people—are being depleted at alarming rates, according to new NASA satellite data that provides the most detailed picture yet of vital water reserves hidden under the Earth's surface. Twenty-one of the world's 37 largest aquifers—in locations from India and China to the United States and France—have passed their sustainability tipping points, meaning more water was removed than replaced during the decade-long study period, researchers announced Tuesday. Thirteen aquifers declined at rates that put them into the most troubled category. The researchers said this indicated a long-term problem that's likely to worsen as reliance on aquifers grows."

Population growth is also placing significant stress on energy and food production, which is further exacerbated by water scarcity. The global population is currently increasing by approximately 70 million people each year. As a result, the total global population is projected to reach 9.6 billion by the year 2050 [25]. The International Union for Conservation of Nature (IUCN) estimates that by 2050, water, energy, and food demands will increase by 55, 80, and 60%, respectively [26].

This growth will increase the pressure on limited water, energy, and food resources. Energy consumption is estimated to increase by 1.6% each year, amounting to an increase of about 36% by the year 2030. Additionally, pressure on agricultural resources will increase through societal habits such as consumption of more livestock and vegetable oils. The number of calories that a person ingests each day is expected to increase from 2373 kcal/person/day in 1969/1971 to 3070 kcal/person/day in 2050. Urbanization will yield more industrialization and water usage, and water demand will increase globally from 4,500 billion cubic meters to 6,900 billion cubic meters by the year 2030. This estimation assumes that the efficiency in water technologies does not improve, and the projected demand is about 40% over our currently accessible and reliable supply [27]. These challenges demonstrate the need for data, nexus solutions, and the combining of emerging solution pathways for technology and services, regional planning, policy and governance, and new behaviors and decisions if urbanization is to be steered toward a sustainable trajectory.

In conclusion, a new set of water and energy ethics are needed to maximize human and ecosystem health and prosperity. Bringing systems together via urban nexus strategies—that amplify synergies, reduce tradeoffs, and can transition resources from scarcity to abundance—will be foundational to a more resilient human, natural, to cyber-physical system that supports diverse activities today and for future generations. As noted, multiple risks, vulnerabilities, and early signs of stress abound. Therefore, the abilities and capacities to harmonize human to ecological needs will require new, integrated ways of using and managing water, energy and other systems and services. Elegant designs will emerge soon, from crises or proactive actions in urban contexts.

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