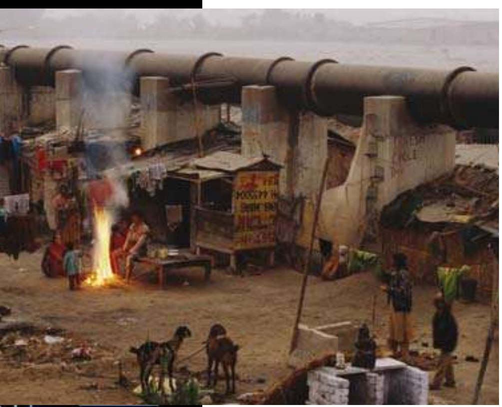
King's College London

HUMANITARIAN FUTURES PROGRAMME

planning from the future

HUMANITARIAN CRISIS DRIVERS OF THE FUTURE:

URBAN CATASTROPHES: THE WAT/SAN DIMENSION



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Executive Summary

Overview

This paper is about the future of water and sanitation stress (Wat/San) in urban slums and how such stress is likely to exacerbate other humanitarian crises over time. It is intended to explore the interlinkages between different crisis variables from a *futures perspective*, i.e., how current trends may evolve to producing surprising new outcomes.

The paper begins in Section 1 with a summary of current water and sanitation issues in urban slums. It then proceeds to map the relationship between Wat/San stress and other causal factors in Section 2, including conflict, political violence, corruption, an epidemic disease. Section 3 extrapolates these relationships into the future using two case studies to explore scenarios of complex humanitarian crisis driven by Wat/San stress. It then concludes with a discussion of the implications of such future conditions for the present day humanitarian sector, ending in Section 4 with a series of recommendations for anticipating and responding to future Wat/San challenges in the present day.

Present Conditions

The rapid growth in urban population around the world has led to a proliferation of urban slums in many developing world cities. UN HABITAT estimates that by 2050, over 5 billion people will be living in cities, with an average of 30% living in slums. The majority of slums lack access sufficient water and adequate sanitation. In 2000, there were around 1.1 billion people (18% of the world population) without adequate water and 2.6 billion people (> 40%) without adequate sanitation). Future projections for water and sanitation are bleak, with most developing countries off-target to meet Millennium Development Goals of adequate water supplies, and increasing numbers of urban dwellers world-wide not expected to have access to improved facilities for water or sanitation.

Access to clean water is recognized to be largely a management challenge, however, not a supply challenge. Sufficient water exists in most cases for adequate water provision. Various institutional, political, and economic barriers prevent water from reaching slum dwellers where and in the ways they need it. Solutions must therefore focus on understanding local social networks and power structures in order to provide the right incentives and delivery approaches if they are to be successful.

Wat/San as a Driver of Other Crises

Lack of clean water and sanitation bring their own crises. Health problems such as malnutrition, diarrhoea, cholera, malaria, dysentery, schistosomiasis, denge fever, typhoid fever, gastroenteritis and hepatitis A and cancers are common, especially when water is mixed with industrial and sewage effluent.

This report focuses on the impacts that water and sanitation stress have as drivers of *other* humanitarian crises. It presents three main arguments for how Wat/San is connected to other dynamics which may combine to produce surprising new crises in the future. These arguments are:

Corruption, exploitation and criminality: As with any valuable good, the provision of clean water and sanitation facilities in slums is an attractive target for corruption, greed, collusion and exploitation. This is particular true where political oversight lacks accountability and enjoys an excessive of discretionary control, resulting in collusion between government officials and private sector water providers. The result is extortionate prices and weakening of civil society, which limits both slum dwellers' ability to raise themselves out of poverty and limits the ability of external actors to change the system. Wat/San stress in slums should therefore be considered a major driver of corruption and capacity reduction, thereby limiting the effectiveness of future response efforts to a range of complex humanitarian crises.

Conflict and political violence: While water and sanitation shortages have rarely caused direct international conflict, there is extensive evidence that water shortage at the local level produces an increased violence and conflict amongst different water users. The threat is especially great in high density, multi-ethnic, politically unequal environments of concentrated poverty; as is often found in many slums. Wat/San stress should therefore be considered as a major driver of criminal and political violence as slum populations struggle to reconcile the differences they see between access to fresh water and clean living conditions.

Increased risk of disease: One of the greatest issues of concern for future humanitarian crises is the potential for new or mutated emerging diseases originating in the world's slums. With constant population churn, close proximity between animals and humans and poor health and sanitation, the opportunities for new disease vectors are huge in most slum areas. The situation is made more difficult due to the lack of adequate surveillance and access to slum populations. Wat/San stress in slums is therefore likely to be a major driver of new diseases and possible epidemics in the coming decades.

Case Studies: Scenarios of Future Crisis

These causal factors were then combined in a series of exploratory scenarios to illustrate how Wat/San issues may produce new crises in the future. Water conflict in the city of Dhaka, Bangladesh was used to illustrate how dissatisfaction and anger at the condition of slum dwellers could be used by various political and criminal groups to produce large scale violence and political instability. High population density, tropical climates and close human/animal interaction without clean sanitation was used to illustrate how an emerging disease could be generated in the slums of Sao Paulo, producing a worldwide Influenza pandemic with startling consequences.

Conclusions and Recommendations

The report concludes with a series of recommendations which outline how the wider humanitarian sector can begin to grapple with Wat/San as a more complex variable in the future. These recommendations include:

Develop business models and engineering solutions that match the social structures and governance networks of slums: Recognize that the most difficult aspect of water provision lies in developing business models and engineering solutions that match the social structure and governance networks of slums. Many urban environments actually have enough water in absolute terms to provide for the needs of their residents. It is therefore necessary to understand the specific incentives and relationships which govern water distribution at the moment before designing a system to interface with existing services.

Acknowledge the level of uncertainty and change inherent in slum social structures: It is therefore necessary to design service delivery models that work with, if not take advantage of, this uncertainty and change. This places the emphasis on light weight, modular, and user-maintainable systems as opposed to large, resource intensive industrial solutions.

Utilise existing networks of slum leadership (legitimate and otherwise) to provide business incentives for the expansion of clean water networks within slums. This can be done by:

Providing modular, incremental delivery systems using low tech, flexible infrastructures to provide transitional service provision. Such systems are low cost and are able to rapidly expand and contract relative to changing conditions, making them ideally suited for slum environments.

Exploring modular, low tech, incremental waste removal and treatment systems: Such systems take advantage of the vast amount of untapped labour in slums and allow for incremental micro-investment and business engagement (i.e., "Pay as you Poo" mobile toilets, bucket by bucket removal services, self assembled dry composting toilets, etc).

Together these findings and recommendations are intended to help humanitarian organizations improve its adaptive capacity moving forward and provide new conceptual frameworks for understanding the causes and consequences of future humanitarian crises.

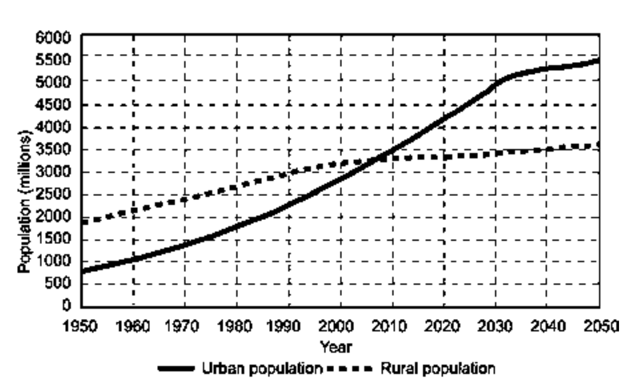
Background

This paper explores the implications of Wat/San stress in slums as a driver of future of humanitarian crises. It is important, however, to recognise that water and sanitation also pose deep and enduring challenges for governments and multi-lateral organisations when dealing with urban areas in general. The lack of resources and consequent inability to address the increasing demands on water and sanitation systems throughout the urban and per-urban areas will not only threaten the viability of cities and towns as a whole, but could transform even relatively viable urban areas into slums. That said, this particular study, while recognising the broader implications of the wat/ san threat to urban areas, has chosen to focus principally on one part of this complex challenge, namely, wat/ san in slum areas. In order to understand this relationship, a thorough understanding of present trends and conditions must be achieved. The following section presents a basic overview of the causes and conditions of both urban slums and Wat/San stress in a way that provides an analytical evidence base for the exploration of future trends.

1.1 Causes and conditions of water stress in urban slums

Urban areas have seen unprecedented growth over the past 60 years, with their populations equalling those in rural areas in 2007 (Figure 1). By 2050, urban populations are projected to grow to 5.32 billion people, with rural populations stabilizing to just over three billion (UN-HABITAT, 2003a, d; Cohen, 2002; UN, 2004b). Ninety-four percent of the projected urban growth is expected to be in developing countries. In addition, approximately 5.2 million refugees live in cities and towns, and this number is expected to grow in the next 30 years (UNHCR, 2009). By 2030, Latin American and the Caribbean are projected to be almost 85% urban, and more than half of all Africans and Asians will live in urban conurbations.

Figure 1: Urban and rural populations of the world: 1950-2050



Note: The number of urban-dwellers exceeded rural dwellers in the mid-1990s, and is projected to increase to 5.32 billion people (out of a total of 8.91 billion people) by 2050. Adapted from WaterAid (2008) and data in UN (2004b) and Cohen (2002).

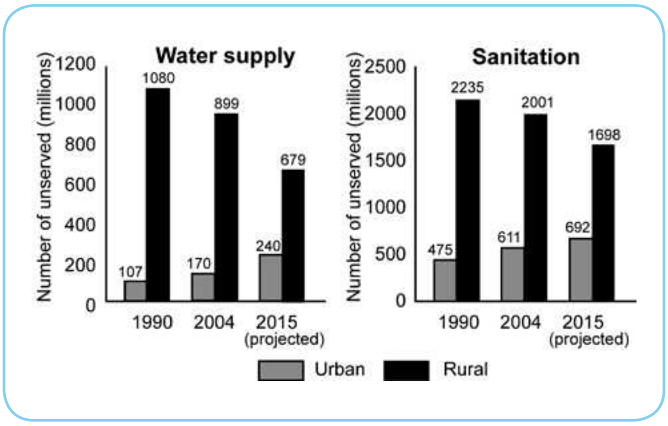
Approximately one of every three urban inhabitants, or approximately one billion people, lives in a slum (UN-HABITAT, 2003 a, b). Half of these slum-dwellers (c. 581 million people) live in Asia. In the least developed countries in Africa, over 80% of urban inhabitants live in slums (WaterAid, 2008). Slum numbers are projected to increase by 25 million per year, and, if unchecked, will reach three billion people by 2050 (UN-HABITAT, 2003 a, b, 2004).

Slums have been defined as 'overcrowded, underdeveloped areas of housing occupied by the poor, unemployed and unemployable', 'densely populated areas, often with poor quality housing and little or no adequate sanitation', or 'squalid and overcrowded urban areas inhabited by very poor people'. Foroutan (2009), for example, defines the five key elements of slums as follows:

- Lack of improved water
- Lack of improved sanitation Insecurity of tenure
- *Fragility of housing stock*
- Insufficient living area

Most definitions of slums highlight their lack of sufficient water and adequate sanitation. In 2000, there were around 1.1 billion people (18% of the world population) without adequate water and 2.6 billion people (> 40%) without adequate sanitation) (WHO/ UNICEF, 2004). These deficiencies have lead experts to coin new terms such as 'water poor' and 'water desperate' (Mara, 2003). Future projections for water and sanitation are bleak, with most developing countries off-target to meet Millennium Development Goals of adequate water supplies (WHO/UNICEF, 2006), and increasing numbers of urban dwellers world-wide not expected to have access to improved facilities for water or sanitation (Figure 2 overleaf).

Figure 2: Global population without access to improved water supply and sanitation in urban and rural areas (projected based on 1990-2004 trends).



Note: Future projections suggest that increasing numbers of urban-dwellers will have reduced access to water and sanitation. Inadequate progress on Millenium Project Goals suggests that the projections for adequate water supply and sanitation between 2015 and 2050 will not improve. Redrawn from WHO/UNICEF (2006).

Water, together with food and shelter, is a basic human requirement. Without adequate provision, people living in urban slums are unable to have enough water for drinking, cooking, cleaning and, in some cases, urban agriculture. In slum areas, the lack of detailed maps showing plot boundaries, roads and paths makes it impossible to design and provide piped water systems. Even if these maps were available, the steep and often poor terrain upon which slums are built, lack of public roads and paths also contribute to difficulties in providing infrastructure (UN, 2006). Furthermore, the lack of land registry information for household populations and ownership means that it is difficult to ensure continuity in payments for water.

When water supplies are contaminated and sanitation is poor, then health problems such as malnutrition, diarrhoea, cholera, malaria, dysentery, schistosomiasis, denge fever, typhoid fever, gastroenteritis and hepatitis A and cancers arise. This is particularly true of slum areas: in Dhaka, Bangladesh, for example, infant mortality rates are higher in slum areas compared to rural areas (Montgomery *et al.*, 2003). The Word Bank has stated that improving sanitation is the most cost-effective public health intervention to reduce child mortality (World Bank, 2006). Other diseases, such as fluorosis, arsenicosis, goitre and malnutrition, are related to excesses or insufficiencies of chemicals in drinking water supplies (Selinus *et al.*, 2005) (Table 2). In Table 2, the diseases related to excessive intake of inorganic contaminants, including arsenic, chromium, fluoride, lead, manganese and nitrates, are related to natural geologic factors and industrial contamination, and are thus specific to particular geographic areas.

Table 1: Examples of diseases arising from ingestion of contaminated drinking water

Contaminant	Diseases
Arsenic^	Melanosis, gangrene, skin and internal cancers
Chromium^	Gastroenteritis, nose damage, bronchitis, lung cancer, renal damage, death
Cryptosporidiosis*	Diarrhea, nausea, abdominal cramps, low fever
Fluoride^	Dental and skeletal fluorosis
Lead^	Neurological damage, renal disease, cardiovascular effects, reproductive toxicity
Manganese^	Neurological problems
Nitrates and nitrites^	Baby-blue syndrome
Pathogenic bacteria*	Typhoid, chloera, dysentary, infectious hepatitis, gastroenteritis

*Note: Compiled from data in WHO (2004) and Selinus et al. (2005). Contaminants marked with ^ are related to geology and industrial contamination, and are likely to have future impacts if groundwaters containing them are over-exploited. Contaminants marked with * are likely to have increased future impacts due to increased urbanization, over-crowding and human waste contamination of water supplies, or if natural disasters increase.*

In the future, the risks arising from these contaminants are likely to increase if potable waters are increasingly taken from groundwaters with naturally-high concentrations of these elements, or if industrial contamination of aquifers increases. The organic contaminants in Table 1 arise when water supplies are contaminated by human sewage or natural pathogens. In the future, such contaminants will cause problems with water quality after natural disasters, and if urbanization, over-crowding and degradation of water infrastructure increase.

1.2 The current global water crisis

The United Nations and other organisations have coined the term 'water crisis' to describe the state of the world's water resources. The water crisis relates to the fact that, although there is abundant water on Earth, only less than five percent (by volume) is available as fresh water. Most of the Earth's water (94% by volume) is in the oceans. Although it is possible to desalinate ocean water to convert it to useable freshwater, the energy and cost requirements for this are currently extremely high, making it possible only for rich nations. The current water crisis exists because:

- most of the large groundwater resources have already been discovered, and are being exploited, exhausted or contaminated
- most of the projected future population growth will occur in areas experiencing the greatest water shortages, and there are no plans for accommodating these increases and
- economic factors are diverting water towards water-intensive industrial and food-producing activities (Jury and Vaux, 2007).

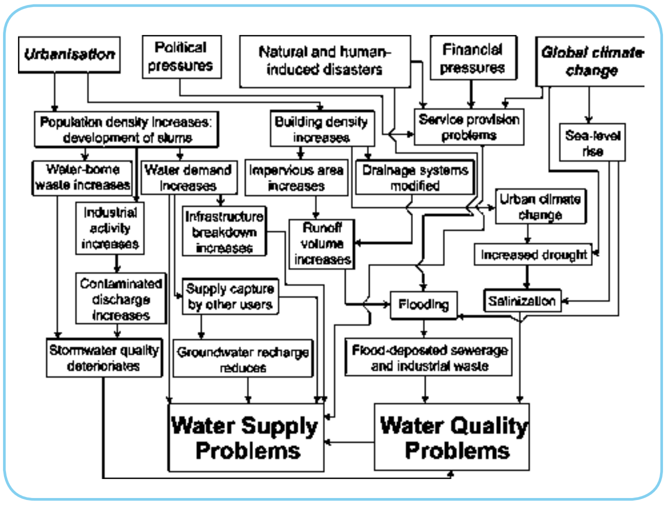
The global water crisis is felt even more acutely in urban slums, where the twin key issues surrounding water relate to its supply and quality. Water supply and quality, in turn, are affected by five current and future crisis drivers, namely, urbanisation, political pressures, natural and human-induced disasters, financial pressures and global climate change, as illustrated in the flow chart in Figure 3.

Urbanisation is accompanied by increases in population density and development of slums. This in turn puts increased demand on water resources, which in turn can lead to water supply problems as supplies are consumed by increasing numbers of people (Figure 3). This was shown in Shanghai, China, the largest city with the highest level of urbanization in China. The UN listed Shanghai as one of six cities that would experience a serious deficiency of water resources in the 21st century. These shortages have been attributed to rapid urbanization since 1979 (Wang *et al.*, 2008). In two decades' time, rapidly growing urban conurbations will likely see the same shortages.

Political and financial pressures can also influence water supply in urban areas. For example, the expansion of urban areas, with their attendant water demands, has meant that water originally designated for rural areas and activities (e.g., irrigation) is diverted to urban areas. In some parts of the world (e.g., Central Asia, Lloubimtseva and Henebry, 2009) land-use change and poor water management have been suggested to be the major influences on present-day water supply. Constructing and maintaining these and other water distribution networks involves co-operation between local, regional and national governments (Gupta and van der Zaag, 2008). If this cannot be achieved, then interruptions to, or cessation of, supply may result.

Over-use and natural factors can cause loss of water supply to urban areas. Intensive irrigation to increase food supplies has caused diversion of resources away from urban areas. Use of water for agriculture is particularly high in meat-consuming, wealthier countries. Natural factors, such as shrinking glaciers, also play a role in water loss. Many urban areas in the world rely on glacier meltwater for their fresh water, such as La Paz, Bolivia, and especially, south-east Asia, where half of the world's population takes its water from rivers fed by

Figure 3: Flow chart illustrating the factors leading to water supply and quality problems in urban areas



Note: Boxes highlighted in bold italic are the major expected crisis drivers for the next 50 to 100 years. Based on Goudie (2001, p. 493).

Himalayan glaciers. These glaciers have shrunk by over 20% over the past 50 years, causing greater summertime flows and severe floods. Future predictions for the coming decades are that the glaciers will disappear here, and in other places around the world, causing drought and, in places, complete loss of freshwater. Loss of glaciers is particularly serious, as they currently provide up to half of the drinking water for 40% of the world's population (Goodman, 2007) HFP's Third Pole Study as part of this package explores this future in more detail.

Natural disasters affecting urban areas include tornados, floods, landslides, volcanic eruptions, earthquakes, hurricanes, blizzards and ice storms, drought and famine, fire, chemical contamination events and technological and transportation disasters (Cross, 2002). Emergencies and natural disasters can cause severe stress to water supply (e.g., loss of supply, breaks in pipelines, damage to structures, water shortages) and quality (e.g., contamination of water by flood-released sewage) (Table 2 overleaf). These water supply and quality effects can be directly applied to slums in urban areas in a variety of geographic settings. Coastal urban areas such as Lagos in Nigeria are vulnerable to hurricanes, with their attendant supply and quality problems, while those in mountainous areas or areas of steep terrain (e.g., Hong Kong) are more susceptible to landslides. Urban areas near earthquake or volcanic zones (e.g., Los Angeles, the Phillipines, are susceptible to the water infrastructure and contamination problems that accompany these natural hazards, should they occur. Flooding and drought are possible in nearly all urban areas around the world.

Water quality problems can arise from a number of sources (Figure 3). Salinization is the building up of salts in waters and soils. This can be cause by drought, where evaporation exceeds precipitation, sea-water incursion due to rising sea-levels, or over-pumping of

Table 2: Effects of natural disasters on drinking water supply and quality

Natural Disaster	Drinking Water Supply Effects	Drinking Water Quality Effects
Earthquakes	Breakage of water tanks, buildings, engine houses, dams, reservoirs, underground pipes, conduits, intake wells, drains	Contamination by simultaneous breakage of drinking and waste water pipes, presence of animal carcasses or discharge of petroleum, industrial or toxic wastes into surface drinking water sources
Hurricanes	Flooding and related damaging or breaking of pipes, above-ground buildings, engine houses and sewerage systems	Flooding and drainage blockage
Flooding	Breakage of pipelines, partially-buried tanks, pumping equipment and electrical installations, intakes, dams, reservoirs and other surface constructions	Contamination by animal cadavers near intakes, excessive increase in water turbidity, human, animal and industrial waste
Landslides	Breakage of all installations, in particular intake and distribution structures located on or in main path of active slides	Contamination by animal cadavers near surface intakes in mountainous areas
Volcanoes	Breakage of pipelines, partially-buried tanks and other installations, surface works and buildings	Contamination by ash, gases, toxic fluids, animal cadavers near intakes or in open water canals
Droughts	Decrease in flow and supply of surface or groundwater	Increase in water salinity, reliance on water from tank trucks, with consequent loss of quality

Note: Urban areas will experience the listed water supply and quality effects depending on their geology (e.g., proximity to earthquake or volcanic zones), location (e.g., proximity to coastal zones that are affected by hurricanes) and terrain (e.g., steep terrains experiencing landslides). Adapted from Pan American Health Organization (1998).

groundwater, mainly for intensive irrigation purposes. Urban centres situated on coasts, such as Alexandria (Egypt), Dhaka (Bangladesh) and New Orleans (USA), are particularly vulnerable to natural (sea-level) salinization (Barrow, 2006), while those further inland, in large agricultural areas, are vulnerable to industrial salinization (Kaushal *et al.*, 2005).

Drinking waters can be contaminated by high concentrations of naturally-occurring and anthropogenically-produced chemicals such as arsenic, manganese and boron. In south and east Asia, nearly 50 million people have been consuming water contaminated with arsenic for several decades (Ravenscroft *et al.*, 2009). The arsenic here is entirely natural. It occurs in fine iron rust coatings on sediment grains in the extensive deltas that Asian urban centres are built on. The arsenic is mobilised from the sediment to waters by the action of bacteria that live in the sediments. The problem arose because of a massive program of tube wells drilling was carried out in the 1970s and 1990s to obtain water free of pathogenic microbes that caused diarrhoeal diseases such as cholera and dysentery. Although the incidence of child mortality from these diseases dropped following this period (Meharg, 2005), many of the wells were contaminated with arsenic. Because arsenic-related diseases such as skin and internal cancers take up to 10 years to be detected, the problem went largely un-noticed until the 1980s and especially, the late 1990s (Das *et al.*, 1994). Sun *et al.* (2004) have estimated that the health of 200 million people in more than 70 countries worldwide is at risk from drinking arsenic-polluted groundwaters. The arsenic and other contaminants can come from industrial activities such as cloth dyeing, coal burning, manufacturing, petroleum refining. In Lahore, Pakistan, Farooqi *et al.* (2007) found excessive concentrations of fluoride, arsenic and sulphur in groundwaters in many districts, including slum areas. These authors attributed the pollution to a combination of sources including air pollution, fertilizers and household waste.

As population densities increase, so too does the amount of water-borne waste. This waste contains high concentrations of faecal coliform bacteria from human or other animal feces. Inadequate or non-existent septic systems can result in the discharge of these bacteria directly to stormwater (sewer) drains, ditches and surface and ground waters. This was demonstrated in Kampala, Uganda, where water quality monitoring for 19 months showed that groundwater was contaminated with thermotolerant coliforms and faecal streptococci from animal and human waste during short intense rainfalls (Kulabako *et al.*, 2007). During periods of high rainfall, sewers that contain such wastes can overflow and deposit the material onto floodplains, which are often occupied by slum-dwellers.

Urban growth also leads to increases in the numbers of built structures (buildings, roads, bridges, etc.). This means that these urban ground surfaces become more resistant, or impervious, to rainfall (Figure 3). This will exacerbate run-off, making it more extreme and unpredictable (e.g., Haase and Nuissi, 2006), and lead to localized flash flooding and overwhelming of sewer systems, which in turn can contaminate water bodies that are used for drinking and urban irrigation. Flooding will be exacerbated by urbanization in another way: that is, that the process of urbanization modifies the urban climate, leading to increased precipitation and heavier and more frequent thunderstorms. In their study of the city of Liepzig, Haase and Nuissl (2007) showed that surface runoff had more than doubled in the city area between 1940 and 2003 due to the increase of impervious surfaces. These authors found a corresponding decrease in the overall evapotranspiration from the soils of the urbanized area. By sealing soils to create built structures, their capacity to soak up contaminants is reduced. Any contaminants deposited on the impervious surfaces will therefore be washed away into receiving water bodies and thus reduce their quality (Xian *et al*., 2007). This was shown by Kim *et al*. (2007), who observed high concentrations of suspended solid, organic and nutrient contaminants in the highway stormwater runoff following heavy rains in Korea. The creation of impervious surfaces also reduces the infiltration of rain to groundwater aquifers and lowers the water table, thus reducing available water supply if these aquifers are tapped to provide piped water to urban areas (Scalenghe and Marsan, 2009). This is proving true in Dhaka, Bangladesh, where Hoque *et al*. (2007) showed that groundwater levels under the city are dropping by one metre per year, partly as a result of the dramatic increases in the numbers of built structures over the past two decades. With urban populations expected to increase over the next two decades (Figure 1), built structures will also multiply as marginal lands become used for housing, roads and industry. This will likely make the problems with run-off and groundwater charge worse rather than better.

Urbanization can also cause problems with water quality. In the Langas slum in Kenya, rapid urbanization has lead to the majority of urban residents living in slums, which in turn have poor water and sewerage systems (Minai-Murage and Ngindu, 2007). Here, the urban poor use pit latrines and draw water from wells, but poor planning has meant that the wells are contaminated by micro-organisms that migrate from the latrines. The slum residents are therefore at risk of water-borne diseases as an indirect result of urbanization. With urbanization projected to increase over the next 20-30 years, this type of problem is likely to become much more common.

The problems of water quality in urban areas, therefore, relate to the natural geology (whether or not geological conditions result in high concentrations of potentially toxic elements to surface and groundwaters), and to anthropogenic activity (agricultural, chemical, refining, manufacturing and energy industries). Proximity to the ocean, elevation and climate only play a role in water quality in terms of salinization and contamination with infectious agents.

1.3 Future drivers of water scarcity

Many international health and non-governmental organisations have set future targets for water and sanitation. WHO/UNICEF set a Millenium Development Goal to halve, by 2015, the number of people without access to adequate-quality drinking water and basic sanitation (WHO/UNICEF, 2006). In 2009, progress on these aims was reported to be slow:

> *"Greater priority must be given to preserving our natural resource base, on which we all depend. We have not acted forcefully enough – or in a unified way – to combat climate change; our fisheries are imperiled; our forests, especially old-growth forests, are receding; and water scarcity has become a reality in a number of arid regions."* (UN, 2009, p. 5)

> *"Rapid acceleration of progress is needed to bring improved sanitation to the 1.4 billion people who were doing without in 2006, with all its attendant consequences for the health of communities and the local environment. At the present rate of progress, the 2015 sanitation target will be missed."* (UN, 2009, p. 5)

Clearly, adequate water supply and quality are contemporary issues, but they are also vital future humanitarian issues. Some current estimates suggest that by 2025 around two billion people will live in areas where water is scarce (WHO, 2000). Two key crisis drivers will add additional water stress over the next 50 to 100 years; namely urbanisation, and climate change (Figure 3).

The increase in urbanisation has been explored in Section 1.1. With world population predicted to rise from 6.1 billion in 2000 to 8.91 billion in 2050 (UN, 2004a, b; Figure 1), this trend towards urbanization, with its attendant water supply and quality problems (Figure 3) is more than likely to continue. Global climate change is also expected to intensify over the next 50 to 100 years (Arnell, 2004). Projected temperature increases and precipitation decreases associated with climate change in some parts of the world will lead to increased drought, and thus affect both water supply and quality (Figure 3). Droughts could become more severe and frequent due to decreases in total rainfall and higher evapotranspiration, precipitation may occur as rain rather than snow in mountainous areas, causing shifts in seasonal supplies of snow melt-related water and contamination may increase as supplies are diluted less in drought-affected areas. Areas that are expected to be most affected include the Mediterranean, parts of Europe, central and southern America, and southern Africa (Arnell, 2004). In other parts of the world, namely southern and eastern Asia, runoff is expected to increase with climate change. These increases will be mainly during the wet season, however, leaving the dry season water-poor. Many of the world's glaciers have considerably shrunk, threatening riverine base flows and urban water supplies in many large urban centers in

South America and south-east Asia, and this will likely increase with more intense global climate change.

Climate change is a global issue, and will affect both urban and rural areas. In urban slums specifically, the effects of climate change are likely to be felt indirectly. For example, urban areas in drought-affected zones will see their supplies decreased as climate change intensifies. If, as predicted, sea-levels rise by several meters, then coastal urban areas may be engulfed, causing migration of displaced peoples to urban areas and salinization of supplies.

1.4 Mitigation strategies to reduce future water and sanitation stress

It has been stated that 'Water insufficiency is often due to mismanagement, corruption, lack of appropriate institutions, bureaucratic inertia and a shortage of investment in both human capacity and physical infrastructure' (UN, 2006). Other groups have suggested that insufficient property rights, government regulations and water subsidies have contributed to the crisis (e.g., Segerfeldt, 2005). Thus, even with current and future pressures outlined in sections 1.2 and 1.3, there are many opportunities to mitigate, be prepared and resilient with respect to pressures on water quality and supply in urban slums. The most important of these are listed below.

- Expand the provision for adequate and affordable infrastructure, maintenance and sanitary services in slum areas (UN Millenium Project, 2005; UN, 2006). Presently, approximately $30 billion is being spent on an annual basis to achieve the MDG of halving the number of people without access to safe drinking water and sanitation by 2015 (Toepfer, 2004). This is not considered to be adequate by the WHO and UNICEF, and by the Water Supply and Sanitation Collaborative Council and the Global Water Partnership, who estimate that an additional $11 billion, and $14 to $30 billion is needed, respectively;

- Raise the price of water to improve efficiencies in its use and generate financial reserves to improve supplies and wastewater systems (Schafer, 2008);

- Allocate sufficient financial resources for simple, effective and affordable technologies for water treatment (Mara, 2003). Experience has shown that these are better deployed at the community or household scale (Schafer, 2008). Schafer (2008) gives the example of the WaterHealth International UV Waterworks technology that disinfects water using ultraviolet light (http://www.waterhealth.com, accessed 19 August 2009). Slum communities, in particular, must have sufficient financial capacity to cover the costs of providing access to adequate supplies of safe water (Milman and Short, 2008);

- Modify water management systems to adjust to decentralised urban sprawl (UN, 2006) and to be prepared for emergency contamination situations (Milman and Short, 2008);

- Adopt catchment-wide water management systems to ensure that withdrawal from aquifers does not exceed recharge, and that water use is shared equitably between all users;

- Involve local government, institutions and populations in the design and maintenance of water supply systems (UN, 2006), especially across political boundaries (e.g., Gupta and van der Zaag (2008);

- Develop more effective systems to legalise and register land tenure in slum areas (WaterAid, 2007) to give dwellers ownership and responsibility for water resources;

- Outside of slum areas, improve efficiencies in irrigation systems to reduce wastage. This should involve the development and use of inexpensive monitoring and control devices, reuse of waste ('grey) water for irrigation, and new water deliver strategies (Schafer, 2008); and

- Provide education, training and research on the safe and responsible use of water resources (Lundqvist, 2000). The need for research has been recognised by the Global Water Research Coalition (GWRC), created in 2002 to address international water issues, and by other bodies such as the US National Research Council (NRC, 2001).

Wat/San stress as a driver of other crises

2.1 Mapping the role of water and sanitation stress in humanitarian emergencies

Section 1 explored various causes of water and sanitation crises in urban slums. The following section explores how these crises may interact with other issues and become drives of new humanitarian crises.

There are four primary dimensions of change which water and sanitation issues will aggravate in the future. These include increased political and social violence, increased likelihood of epidemics, and a reduced capacity to deal with these crises as a result of diminished economic capacity and increased urban corruption. Each is explored individually in more detail below, concluding with a discussion of how these drivers could interact to drive new, more complex and challenging humanitarian disasters in the future.

2.2 Increased corruption, exploitation and criminality

As with any valuable good, the provision of clean water and sanitation facilities in slums is an attractive target for corruption, greed, collusion and exploitation. Klitgaard (1988) defined corruption by the equation, *Corruption = Monopoly + Discretion – Accountability.* This is certainly the case with water and sanitation in slums.

Plummer and Cross (2008) believe that water supply is an inherently attractive medium for corruption. They write, "investment involves a large flow of mostly public money, often with inadequate planning and oversight. In developing countries, funding sources for projects are often uncoordinated and spending and decision-making are non-transparent." Even in non-conflict situations such as those outlined above, criminal corruption and exploitation of slum dwellers is common place. Plummer and Cross go on to detail some of the ways in which water supply in slums falls prey to corruption. These include:

- Corruption between *public officials and other public officials,* including corrupt practices in resource allocation such as diverting funds intended for water supply for other use, using bribery and political favour to get transfers or lucrative appointments, etc.
- Corruption between *public officials and private actors,* such as happens in licensing, bid-rigging, procurement and construction of water and sanitation systems, or in access to water or distribution rights themselves for private resale.
- Corruption between *public officials and users/citizens/consumers*, whereby officials circumvent the rules for either their own benefit or to enable consumers to get more or better water more cheaply or rapidly.

The WHO and UNICEF estimate that corruption adds between 10% and 30% to the cost of water provision globally. But this figure is much higher in slums, where poor residents must pay up to 10% of their annual income on water alone (UNDP, 2006). Bottled water can cost up to 1,000 times more than tap water in the slums of Delhi, for example (IRIN, 2009). This price differential is not an artefact of real cost, however. High prices and restricted access are often an intentional by-product of organisations and individuals exploiting loop-holes in the system, outright subverting it, or simply taking advantage of those in a weaker position.

Sohail and Cavil (2008) write that, "poor people without water are trapped in a desperate, daily struggle for survival to access water and other basic needs." They go on to observe that the financial poverty of slum dwellers goes hand in hand with political marginalisation, low social status and unequal power relationships. This both aggravates their condition and limits the tools that are available for slum dwellers to take action against corruption. On the supply side, government officials, NGO's or private corporations seeking to provide clean drinking water or hygienic standards is slums often find their efforts blocked, subverted or outright sabotaged. Sohail and Cavil provide an example from India, whereby a local water vendor was also a local politician who sat on the municipal water board and was also "appointed" leader of the resident's committee for a new NGO financed water pump. Concerned that the free water was undercutting his revenue stream, the pump was mysteriously vandalised one night and never repaired (Sohail and Cavil, 2008). A World Bank study from 1998 found over 30 *mastaan* groups in Dhaka, Bangladesh, defined as an organised semi-political gang involved in both local politics and black market economies. The report estimates that such groups employed over 30,000 people directly and many more indirectly, stating that such groups, “maintain links with the political system and the police and are able to maintain an alternative power structure.”

> *“The record of service delivery by institutions and state agencies has been dismal and in their absence, it has been the mastaans or the informal local power brokers in different areas that have stepped in and taken advantage. They provide services for a fee and function as the middleman between the people and service providers. They are often the only service providers in the area and are known for extortions and bribes from people. In order to secure their own power and position, they actively work against NGOs who work for people’s empowerment and often don’t allow NGOs to come into areas that are their stronghold.”*

In addition to raising prices and preventing fair competition and service provision, such multi-level corruption has long lasting effects on a slum’s economy and society. First, it limits both slum dwellers’ ability to raise themselves out of poverty, thereby keeping them locked in a cycle of ever increasing exclusion, and second, it limits the ability of external actors such as governments, NGO’s and private corporations to change the system either.

This simultaneous acceleration of social alienation and economic exclusion, coupled with a decreased capacity to on behalf of the authorities, presents a double edged risk for future humanitarian crises. First, it lowers the adaptive capacity and resilience of slums themselves, making them more prone towards violence, extremism and long term dysfunction. Second, it diminishes government’s ability to respond to complex urban crises in the future, thereby potentially magnifying their impact. Corruption, exploitation and organised water criminality are all inherent dynamics in most slums, but will become even worse as the amount of fresh water declines due to climate change.

2.3 Increased conflict and political violence

Extensive research has been conducted on the role of water stress on inter-state conflict. Giordano and Wolf (2002) reviewed the history of violent conflict in the 20th Century and concluded that interstate violence was rarely if ever caused by, or even focused explicitly on, water resources. Hamner and Wolf (1997) observed that, “organized political bodies have signed 3,600 water-related treaties since AD 805, versus only seven minor international water-related skirmishes (each of which included other non-water issues).” They note that:

> *“Historically, formal and informal international political institutions managing water have adapted to increased scarcity without resorting to the expensive and inefficient means of war to secure water supplies. Instead cooperation, through multiple means, somehow emerges between states.”* (Hamner and Wolf, 1997)

While this may change in the future, strong historical evidence suggests that it is therefore unlikely that states will go to war exclusively over water in the near future. Such a scale is beyond the scope of this analysis as well. Unfortunately there is marked evidence of water-related conflict at the intra- and inter-urban levels. Fisk and Yoffe (2007) observe that most current conflict surrounding water supply occurs at the subnational and intra-urban levels, such as in Cochabamba, Bolivia, where riot police fought with protestors for two days over the privatization of the municipal water supply in February, 2000. Another example is the April, 2001 protests in Karachi, Pakistan, where slum residents clashed with police chanting, “Give us water!”

These types of conflicts are far more personal, intimate, and involved than regional water disputes. A 2009 IRIN report on humanitarian crises in urban environments quotes a slum dweller from Delhi, relating her experience of water conflict in her slum, “You should come here early in the morning to see the long queues and the fights. Some women bring sticks to fight for the water. There is never enough.” (IRIN, 2007). HFP interviews conducted as part of a recent mission in India add nuance to this level of conflict. One interviewee related an anecdote about emerging conflicts between the water demands of exclusive residential developments and tourist resorts in Bangalore and local communities who depend on the water for livelihoods. Another cited examples of industries being forced to close due to protests from local communities over the impact on their water supplies. Similarly, in Chennai, a city which has long faced chronic water shortages, farmers in the surrounding areas, rather than becoming victims are increasingly selling their water to companies supplying the city. A common theme was the current inadequate understanding of the complexities surrounding water conflicts at the local level.

At their most basic, water conflicts in slums have been described as simple scarcity problems, whereby the objective is simply relief from want (Homer-Dixon, 1994). But Homer-Dixon distinguishes other dimensions water conflict that have more profound implications as potential drivers of violent conflict within slum environments. He observes that on top of the simple scarcity problem, water conflicts often escalate into “group identity conflicts” and, if unaddressed, larger conflicts of “relative deprivation”. Relative deprivation problems have the potential to turn violent when, “1) there are clearly defined and organized groups in a society; 2) some of these groups regard their level of economic achievement, and in turn the broader political and economic system, as wholly unfair; and 3) these same groups believe that all peaceful opportunities to effect change are blocked, yet regard the balance of power within the society as unstable; that is, they believe there are structural opportunities for overthrowing authority in the society.” (Lichbach, 1989)

Summarising the early work of Homer-Dixon (1995) and Bächler (1995), a review by the OECD produced the following table of causal factors. They argued that centralised, multi-ethnic, high density, politically unequal environments of concentrated poverty have the highest potential for civil violence under conditions of environmental resource change. As outlined in Section 1, this describes the conditions of modern slums with great accuracy.

Describing the potential outcomes, Homer-Dixon writes that,

> *"these pressures might overwhelm the management capacity of institutions in developing countries, inducing praetorianism or widespread social disintegration. They may also weaken the control of governments over their territories, especially over the hinterlands [or in slums]...The regimes that do gain power in the face of such disruption are likely to be extremist, authoritarian, and abusive of human rights. Moreover, the already short time horizons of policymakers in developing countries will be further shortened. These political factors could seriously undermine efforts to mitigate and adapt to environmental change. Soon to be the biggest contributors to global environmental problems, developing countries could become more belligerent, less willing to compromise with other states, and less capable of controlling their territories in order to implement measures to reduce environmental damage."* 1991

The manifestations of environmental and economic scarcity can already be seen in many of the world's slums today. Drawing again from a recent HFP mission in India, interviewees discussed water and sanitation issues in the following way:

> *"The crisis in urban areas is not just about increasing numbers, but how different groups shape the politics [...] These crises [areas of the city without water and sanitation, high infant mortality] are not a natural construct arising from population increase; that does not tell you anything." The problems of a huge gap between areas of the city that have access to infrastructure and those that do not is "no longer in the technical realm... but in the dimensions of how the elites interact with the lower income groups and who pays for it".*

Under such conditions of political competition, it is inevitable that both organised and more opportunistic conflicts will occur. It is also likely that various political and criminal groups will be strengthened by such tensions. This could take several forms; on the more organised end of the spectrum, it is likely that Wat/San crises will contribute to or strengthen the formation of cartel-like ideologically driven political movements such as Hizbollah or Somali warlords in Mogadishu.

On the more anarchic, disjointed side, there is already an explosion of criminal gangs such as those found in the slums of Latin America, Central America and many African states.

On the whole, the impact of such conflict is stark. UN-HABITAT estimates that total worldwide crime rates increased 30% between the years 1980–2000. Crime rates, especially violent crimes, are much higher in slums. A 2008 Amnesty International report on crime in Jamaican slums reports that 1 out of every 2000 people die by gunfire each year, a figure nearly ¼ of the estimated civilian death rate in Iraq.[1] In Jamaica, as in many other slums, these crimes are deeply tied to political, ethnic, and economic turf battles. Armed and highly organised gangs exchange political support for to politicians in exchange for profitable government contracts, extortion and protection rackets, and other quasi-legal or illegal activities. The same is true in the favelas of Brazil or the warlord territories of Mogadishu. A 2007 IRIN observed that, "For the well-off there has been a rapid growth of the private security industry and of urban gated communities. The urban poor often have to fend for themselves as whole sections of slums are no-go areas for police and where gangs and militias rule."

Section 1 outlined the growing threats of water and sanitation shortages in the urban slums of the future. As a fundamental necessity of human life, it is clear that water and sanitation stress in slums will compound the political and social tensions already brewing, with potentially explosive implications.

1 The civilian death rate in Iraq was estimated by dividing the total estimated number of civilians killed since 2003 (between 93,000 and 101,000, according to the Iraq Body Count Project) by the total estimated 2008 population (approximately 28 million), for a rate of nearly one civilian death per 340 residents.

Table 3.

Contributing Factors	Link to Intrastate Violent Conflict	Link to Interstate Violent Conflict	Strength of Relationship
Plolitical System	Probability of violence varies inversely with the degree of democratisation	Stable democracies are unlikely to experience violent conflict with one another	Strong
Geographical Contiguity		Neighbouring states are more likely to experience conflict than non-neighbouring states	Weak
Ethnic Fragmentation	Probability of violence increases with the degree of ethnic fragmentation	Ethnic linkages across borders increases the probability of conflict diffusion	Strong
Population Density	Probability of violence increases with population density		Strong
Power Status		If there is a substantial difference in power status, the probability of violence increases	Medium
Previous Conflict	Violent conflict in previous two years increases the probability of violence	Violent conflict in previous two years increases the probability of violence	Strong
Level of Economic or Human Development	Probability of violence varies inversely with the level of development		Strong
Resource Scarcity	Probability of violence increases with increased levels of resource scarcity	Probability of violence increases with increased levels of resource scarcity	Weak
Vulnerability to Natural Disasters	Unknown		?

2.4 Emerging epidemics

Previous sections explored the social, economic and political dimensions of change which increased water and sanitation stress may bring about in urban slums. The third critical danger related to water and sanitation as a driver of future humanitarian crises is epidemic disease. Open air sewage, lack of clean bathing water, and close contact between species in dense animal-human interactions make slums a breeding ground of tomorrow's pathogens.

Studies by Szwarcwald *et al.*, (2002), Sclar *et al.* (2005) and many others indicate that almost all health outcomes are worse in slums than in neighbouring areas. These and most other studies documenting the impact of poor sanitation and overcrowding on infectious disease prevalence in slums rely on observed clinical visits. Unger and Riley (2007) emphasise that in addition to the increased infection burden, the lack of adequate prevention and treatment facilities exacerbates disease occurrence in slums, resulting in devastating waves of infections which haven't been seen in the developed world since the Industrial Revolution. In Angola in 2006/2007, for example, a cholera outbreak in an informal settlement claimed 2,722 deaths out of an estimated 67,257 cases; making it one of the deadliest disease outbreaks in modern history (WHO, 2007).

The water/sanitation vector is of particular importance for these diseases. A 2009 report by Development Alternatives states that 4000 small and medium cities in India are, "on the verge of some humanitarian and health crisis unless immediate action is taken regarding waste management and sanitation". When water supplies are contaminated and sanitation is poor, then health problems such as malnutrition, diarrhoea, cholera, malaria, dysentery, schistosomiasis, denge fever, typhoid fever, gastroenteritis and hepatitis A. This is particularly true of slum areas: in Dhaka, Bangladesh, for example, infant mortality rates are higher in slum areas compared to rural areas (Montgomery *et al.*, 2003).

Of greatest concern for future humanitarian crises is the potential for new or mutated emerging diseases originating in the world's slums. Emerging pathogens are those that have appeared in a human population for the first time, or have occurred previously but are increasing in incidence or expanding into areas where they have not previously been reported (WHO, 1997). Re-emerging pathogens are those whose incidence is increasing as a result of long-term changes in their underlying epidemiology (Woolhouse, 2002). The WHO reports that by these criteria, 175 species of infectious agent from 96 different genera are classified as emerging pathogens. Of this group, 75% are zoonotic species, which means that they can be transmitted from animals to humans; many of which are water-borne.

Despite these threats, relatively little is known about emerging risk vectors in slum communities. Riley *et al.*, (2007) note that in many countries, "disease burden or mortality information on slum dwellers is largely based on clinic, hospital, or national mortality registry data. These end point data represent only the 'tip of the iceberg'." The informal, unorganised, and difficult to access conditions of urban slums only amplify this challenge. With constant population churn, inadequate surveillance, and poor health and sanitation education, the opportunities for new disease vectors are huge in most slum areas.

Case studies: Scenarios of future crisis

Two demonstrative scenarios are presented in this section, outlining fictional but plausible stories about how water and sanitation challenges may lead to more complex humanitarian challenges such as those outlined in Section 2. The scenarios are based in Dhaka, Bangladesh and Sao Paulo, Brazil, each exploring dimensions of conflict, corruption and disease aggravated by water and sanitation stresses.

3.1 Dhaka 2030: Corruption and conflict caused by water stress

Dhaka, Bangladesh has an estimated 1,925 slum areas within its borders (Center for Urban Studies, 1996), home to nearly 3.5 million inhabitants (40% of its inhabitants). It has also been estimated that over 500,000 people move to Dhaka each year, many of which pour into these slum areas. According to the Dhaka Water and Sewerage Authority (DWASA), the city experiences a 25% shortfall in daily water needs. Certain slum districts experiencing markedly higher ratios. By 2030, Dhaka's population has surged to nearly 30 million people. Rising sea-levels caused massive flooding of the coastal area of Bangladesh (Figure 7 overleaf), forcing displaced coastal populations into Dhaka. These so-called "water refugees" poured into the overcrowded slums, aggravating an already dangerous situation.

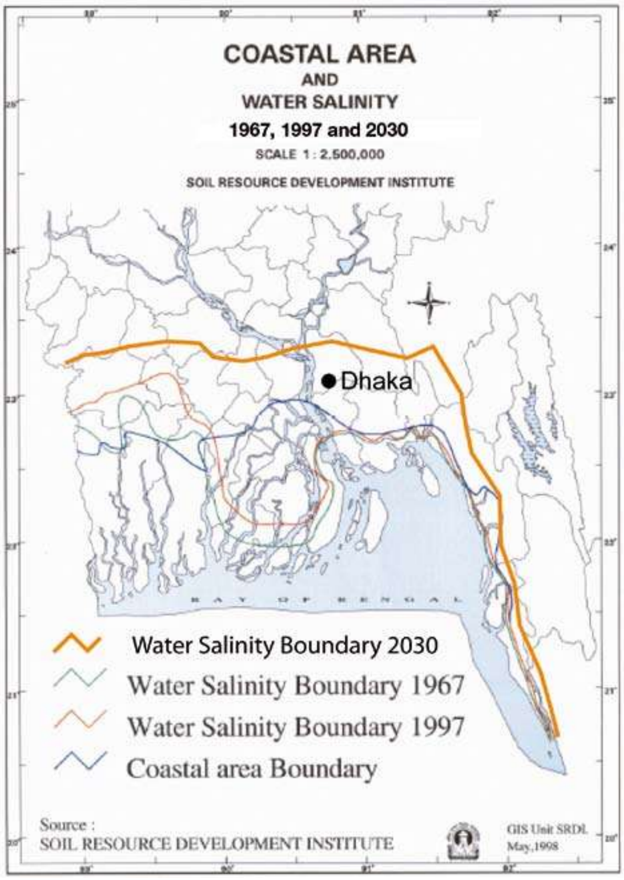
In 2016 the Dhaka City Corporation (DCC) raised over $175 million USD for a large scale upgrade of the city's water supply infrastructure. Focusing mainly on water purification plants along the city's rivers, these projects were intended to provide fresh water for the city's new and existing residents. The procurement of the funds from various sources was hailed as a major breakthrough for the city's water problems and gave the ruling Awami League a political huge boost. But the dream soon turned sour when action failed to follow procurement. Although several sites were cleared by 2020 and construction of one of the plants had begun, this plant was planned to provide water for the wealthier districts of Dhaka only. By the time this plant came online in 2024, the remaining plants intended to serve the city's slums were still not complete. Demands from the media, opposition political parties, and various slum dwellers associations soon uncovered that the remaining funds had been siphoned off for other projects or simply disappeared, leaving inadequate resources to complete the plants and infrastructure necessary to serve the bursting slums.

Anger grew when the news became public that the new water purification plants were unlikely to be completed any time soon. Worse yet, it was revealed that local water merchants and *mastaans* (criminal strong men and gang leaders) had provided payments to key civil servants to delay construction and then arranged elaborate embezzlement schemes to extort money through false construction contracts. Enraged slum dwellers took to the streets in hundreds of uncoordinated riots through-out the city. Nearly 120,000 people marched on DCC Headquarters in a week long violent protest. The Government was forced to call in the military and violently suppress the protests, resulting in over 8,000 deaths and nearly 40,000 arrests.

This brutal crackdown fuelled the flames of anger and resentment within the slums. Ironically, this resentment strengthened local mastaans, many of whom were already allied with various opposition political parties through graft, extortion and bribery rackets. Sensing an opportunity to strengthen their hold on various territories and markets, rival gangs began organizing explicit political rallies, using the issue of water deprivation and unsanitary conditions as their primary rallying issue. The Purba Banglar Communist Party (PBCP) was able to attract particular support with inflammatory class based rhetoric focusing on direct action against specific politicians, businesspeople, and wealthy neighbourhoods.

By the summer of 2026 the PBCP and various other militant mastaan groups had assembled an informal militia of over 60,000 people, spread throughout the slums of the city. Motivated by class resentment, anger, political aspiration and in some case, religious ideology, these groups began a widespread campaign of terror and crime against the DCC. In one incident a force of nearly 1,500 armed slum dwellers seized a dozen police stations around the city, detonating bombs in various markets and bringing the city to a stand-still for nearly two weeks. Shortly after a new housing development for wealthy Bangladeshi's was firebombed just after completion and a major new office call centre complex was subject to sustained siege; killing nearly 150 of the workers trapped inside. The kidnapping and execution of various politicians and civil servants rose to a peak

Figure 7: Soil salinity intrusion map for Bangladesh



Note: Adapted from Climate Change and Strategic Adaptation Provisions for Coastal Bangladesh. Mamunul H Khan; Golam Mahabub Sarwar; Dr Jinnahtul Islam. 27 February 2008. IDB Bhaban, Dhaka, Bangladesh.

in the summer of 2027, forcing the Mayor of Dhaka to declare a state of general emergency and martial law.

This declaration did little to stem the tide of violence. The city's slums were basically ungovernable at this point. All the while health and safety conditions within the slums continued to decline. But instead of targeting the gang and terrorists groups who were responsible for this perpetuation, slum dwellers directed their rage at more visible signs of excess; notably Dhaka's wealthier neighbourhoods and districts. Organised violence, criminality and conflict drove Dhaka's mortality rates through the roof, rendering some neighbourhoods little more than warzones. Extortion, protection rackets, and outright theft and property destruction drove most investment from the city and caused a general economic slump.

The situation reached a tipping point in the summer of 2028. A city-wide election was held to elect local ward leaders and vice-mayors. Gang supported PBCP leaders won by a landslide in most wards, despite obvious documented cases of fraud. But the city erupted in violence when the incumbent government nullified the elections and called in the military with support of the national government. Days later, an organised force of gang sponsored suicide bombers drove three truck-loads of fertilizer explosives into the Bangladeshi Parliament building, killing the Prime Minister and over 100 of its members. The nation was teetering on the edge of a civil war, fuelled by unequal access to basic services and inflamed by rival warlords seeking to expand their power. Meanwhile, hundreds of thousands of the nation's poor went without water or sanitation, the very issue which had sparked the instability in the first place.

3.2 The favelas of Sao Paulo deliver a new form of Influenza

Over one million people are estimated to live in the favelas of Sao Paulo. As with other slums, the majority of these residents experience severe water and sanitation stress. Many also live in very close quarters with other humans and animal species; leading to a perfect "Petri dish" for interspecies viral mutation.

In this scenario, poor sanitation and high population densities leads to a new outbreak of virulent influenza, which would come to be known as H6N1 to scientists. The crisis began in December, 2015, when a wave of pigs and poultry in one of Sao Paulo's largest slums fell ill. The infected animals were lethargic, exhibiting high fevers and hemoraging mucus membranes, followed quickly by death within a day (Yu et al, 2007). Although the owners of the animals were concerned, they were disconnected from official health and sanitation networks and were unable or unwilling to report the deaths the authorities. But within weeks the disease had spread to humans and aid workers within the slum began to notice a spike in flu-like symptoms. By this point several weeks had passed and the virus had reached beyond the confines of the slum and was already spreading through-out the country. By the time the WHO teams arrived in the country on December 12th, the first human outbreaks were already occuring and additional reports were coming in from other parts of

Figure 8: The H6N1 Influenza variant

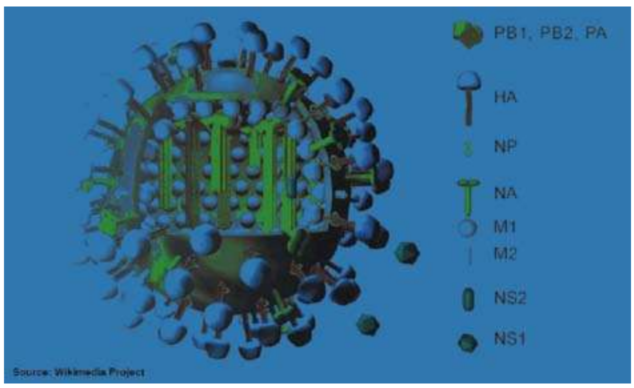
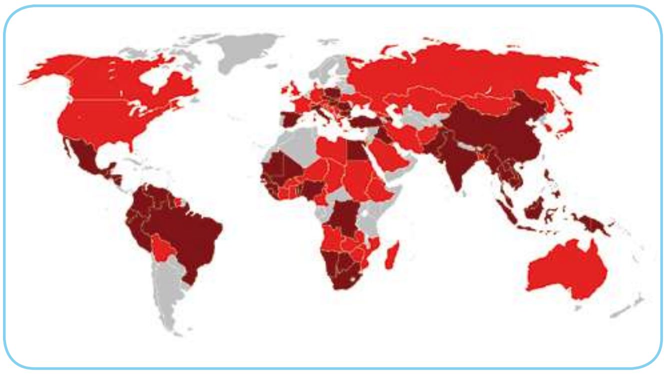


Figure 9: Areas impacted by the virus



Note: Dark red indicates severe mortality.

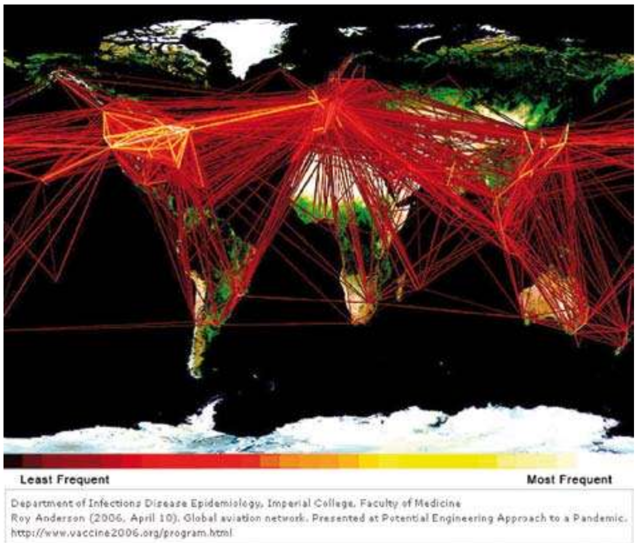
South America, Mexico, and Miami and New York. The team immediately realised a crisis was brewing and the WHO immediately raised the pandemic alert to Phase 4, noting a new strain in animals which also appeared in a small number of human beings (WHO, 2008).

The situation deteriorated swiftly from there. The new H6N1 form of the virus was particularly infectious, with an estimated transmission rate of over 60%. It was also particularly deadly; over 2% of those contracting the disease died within a month (Ungchusak *et al.*, 2005).[2] The vast majority of the exposed population had no immunity to this new mutation, makign them even more vulnerable. While significant efforts had been poured into the preparation of anti-viral medicines and vaccine research, the medical community's attention had been focused on preparing vaccination for the H1N1 variant, which rose to prominance years earlier in 2009. But the genetic material of the H6N1 mutation was sufficiently different that even these preparations proved ineffective.

Victims experienced similar symptoms to the 'Spanish Flu' outbreak of 1918 (Patterson and Pyle, 1991). These included lethargy, cough, fever and high temperatures, followed by hemmouraging from the nose, stomach, and intestines, and secondary infections of bacterial pneumonia which usually killed the victim (Taubenberger *et al.*, 2006). Although anyone was vulnerable to infection, it was the poor and the under-nourished that were hit the hardest. Previous studies found that malaria and malnutrition increased the chances of death significantly. Those with HIV or other immuno-difficiencies were particularly affected, comprising nearly one third of the death toll in 2015.

By January 15th 2016, the virus had spread to nearly 80 million people worlwide. Carried abroad by international long distance commercial flights, the illness leap-frogged out of Asia and appeared in Hong Kong, London, Paris, Marseilles, North Africa, New York, Beijing, Calcutta and Dubai almost simultaneously. By the Febuary of the new year, the number of affected had risen to 390 million.

Figure 10: Global aviation pathways which spread the infection



The economic costs were staggering. Economies in the developing world, particularly those who lost large portions of their population, were reduced to 20 or 30% of their previous levels. Labour shortages, production incapacity, distribution restrictions and a falling demand undid much of the progress made in the global distribution of goods since the turn of the millennium. Worldwide economic losses were estimated at over 20%.[3] Stock and equity markets collapsed as frantic investors attempted to shift resources into more stable long term value that might outlast the pandemic. Demand shocks, in the form of changed preferences, less trust for overseas products, and loss of income and wealth exerted a major pull on the world economy. The supply shocks were greater, however, resulting from the lost labour and transport disruption. As a result, costs in all economic sectors rose and spending declined.

By the end of the crisis, over 140 million people had died, nearly four billion people were affected, and the face of global commerce was changed forever. The social and economic damage left many of the world's poor even more vulnerable to other, more standard crises. The international humanitarian community itself was severly affected as well; many members of international aid and policy organisations were themselves afflicted, severly reducing their response capacities.

2 Compared to smallpox mortality of 20-25%, for example, or previous H5N1 Influenza mortality rates of 0.1%.

3 Extrapolated from the Brookings Institute report, "Global Macroeconomic Consequences of Pandemic Influenza" accessed online at: http://www.brookings.edu/papers/2006/02development_mckibbin.aspx

Conclusions and recommendations

4.1 Wat/San as a driver of new humanitarian crises

This paper has explored the ways in which water and sanitation challenges in urban slums will act as catalysts for other, more complex humanitarian crises. It has argued that water and sanitation challenges themselves are formidable, but that their impact on other social, political, and epidemiological systems are equally significant. The following recommendations explore ways in which humanitarian organizations can act to help mitigate these consequences and improve their ability to anticipate and respond to potential crises.

4.2 Recommendations

1 *Develop business models and engineering solutions that match the social structures and governance networks of slums:* Many urban environments actually have enough water in absolute terms to provide for the needs of their residents. The challenge is how to equitably manage and distribute this water. In order for new solutions to be effective they must properly understand and interface with existing management structures, power relationships, and governance networks within slums.

   Many modern infrastructure solutions are technology driven and ignore the essential dimension of social networks and relationship structures. As a result they often encounter resistance or lack of maintenance. If new systems are to be developed, they must begin with a deeper understanding of who controls water distribution now, what their relationship and obligations are; both to their customers and their other creditors or "bosses", and what political pressures and business models will encourage these players to participate in and expand upon new solutions. New water and sanitation projects are almost certainly at risk of failure should these social dimensions be ignored.

2 *Acknowledge the level of uncertainty and change inherent in slum social structures:* Modern slums experience a constant ebb and flow of new residents, opportunities, and constraints. Anecdotal evidence suggests that political favour and economic position shift at a rapid rate relative to changing populations and internal political workings, the dynamics of which will be largely uncertain or opaque to the outside observer. It is therefore necessary that this level of uncertainty and change is explicitly acknowledged if appropriate solutions are to be developed to meet the water and sanitation challenges of slum environments.

   The best way to design service delivery models that work with, if not take advantage of, this uncertainty is to *not design the system at all*. Put another way, the tactical opportunities and constraints most slum environments are such that no map or Excel based business model will be able to capture the relevant variables. It is therefore necessary to develop systems which can be *self-deployed* in an emergent fashion, bit by bit, by those in the slums with intimate knowledge of where deployment opportunities lie and what can be done to exploit them. This *micro-infrastructure* approach is similar to the financial model taken by the Grameen Bank, relying upon local relationships and local knowledge to deploy a modular, self-assembling banking system which the users themselves design and maintain.

   Such an approach to water and sanitation provision is based on a fundamentally different perspective to service provision than traditional large scale infrastructure projects. Traditional projects are capital intensive, centralised, bureaucratic, and based upon 19th Century Victorian models of social, economic and ecological organisation. Decentralised, bottom-up, incremental micro-infrastructure projects embrace a 21st *Century network-centric* philosophy which takes advantage of the uncertainty and dynamism of slum environments to produce a locally optimal solution without explicit design and management oversight.

3 *Utilise existing networks of slum leadership (legitimate and otherwise) to provide business incentives for the expansion of clean water networks within slums:* In order to achieve these goals it is necessary to build relationships with existing leadership factions within slum environments to produce business models which they can profit from.

There are many ways that this can be done. We outline two possible solutions below:

a *Provide modular, incremental delivery systems using low tech, flexible infrastructures that support transitional service provision:* Following the principles outlined above, it is proposed that water delivery systems within slums must be able to be lightly, cheaply, and rapidly deployed. It is also necessary that they be flexible, to connect and disconnect various households and districts with very low cost and effort as slum conditions change and grow over time. Finally, they must be modular, so that even a single new household can be added should additional resources become available and without the need to redesign the entire system.

One way to do this is through the use of modular segmented, flexible rubber hoses. Such hoses are available in diameters from 1" up to 60", can be produced in sections from one foot to up to 100 feet in length, and have a range of industry standard elbows, cuffs and junctions. They are also produced by dozens of independent corporations internationally, can be maintained and serviced on site by unskilled technicians, and offer nearly endless design options.

Such a system could plug easily into existing municipal infrastructure, allowing dynamic redesign of systems to accommodate changing demand, affordability or social relationships. They could be run directly to individual households, to communal pumping facilities, or to larger volume centralised distribution points. The benefit of the system is that it does not require extensive engineering or pre-planning and can be deployed practically overnight into an endless array of networks and service options. It therefore has tremendous advantage in terms of cost and deployability in slum environments, providing a range of income streams for various levels of society.

b *Explore modular, low tech, incremental waste removal and treatment systems:* In addition to water provision, similar modular, self-designed approaches can be used to address the challenge of waste removal and treatment. Because human biological waste is essentially a decentralised production process (i.e. person by person and household by household), such an approach is particularly well suited to the dynamic environment of slums.

One example of how such a system might be designed is to take advantage of traditional "night closet" or chamber pot social arrangements. Before the invention of water-carried wet sanitation, many Asian countries employed a specific class of workers to manually collect biological waste during the night. This was often done with a horse and cart and entailed transferring waste from a chamber pot or night closet into a barrel for disposal elsewhere.

Modern technology offers many improvements on such a system but retains its basic simplicity and effectiveness. First, antibacterial plastic buckets made from cheap commercially available plastics such as Microban offer an improvement on the traditional chamber pot. If such buckets were fitted with mechanically sealing covers such as those in many commercial compost bins, they could be sealed between use and improve overall sanitation and cleanliness within the household. This would avoid the direct dumping of human waste into public streets and canals, thereby lowering the pollution of water tables and living environments. Handles on the top of the bucket would allow easy portage and collection. Waste would then be carried by hand or cart to an appropriate dumping point (say a municipal sewer on the edge of the slum), cleaned either by hand or through the use of semi-automatic hot water and bleach stations and then delivered again to the family for re-use.

As in the 19th Century, the leasing, collection, emptying and cleaning of such buckets offers a range of discrete business opportunities. Families or individuals could lease buckets and collection service packages relative to their means; wealthier families could afford more frequent pickup or more comfortable buckets, while less wealthy families could opt for lower service grades. The leasing and distribution of such buckets would provide micro-entrepreneurs with a sustainable income stream, while the collection, disposal, cleaning, and return of the buckets provide discrete economic opportunities at every step in the chain. Such systems take advantage of the vast amount of untapped labour in slums and allow for incremental micro-investment and business engagement (i.e., "Pay as you Poo" mobile toilets, bucket by bucket removal services, etc), instead relying upon centralised government to finance, design, build, developing and operating a large, wet sanitation system.

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Technical Appendix

6.1 Classification of water quality and supply vulnerability in urban conurbations

The crisis drivers outlined in section 1.3 are used to develop Table 4, which relates physical and human geography factors to potential future problems in water supply and quality. Two copies of the table are presented; a general example (Table 4) and an example for London, UK (Table 5). The general table (4) will be discussed first.

The table is essentially a matrix that links geographic properties of urban conurbations to their future potential problems with water supply and quality. The physical geographic factors used are proximity to surface water (ocean or river), elevation (< 100 m, 100-2000 m, > 2000 m), climate and geology. The human geography factors are urban (population and building density, and GDP) and industry (agriculture, chemical, refining, manufacturing and energy). The water supply problems are those outlined in section 1.2 and Figure 3, namely flooding, drought, overuse, loss of supply and insufficient or degrading infrastructure. Water quality problems include salinization, and contamination with organics, metals and metalloids, nutrients, excess heat (thermal) and sediment.

Many urban conurbations are situated near bodies of surface water, which are used for transport or sources of drinking or irrigation water, or both. Proximity to surface water does, however, bring with it flooding hazards, creating problems with water supply, or salinization, creating problems with water quality. This is true of both oceans and rivers. River water, too, is often contaminated with excessive sediment, particularly during floods, which can cause quality problems.

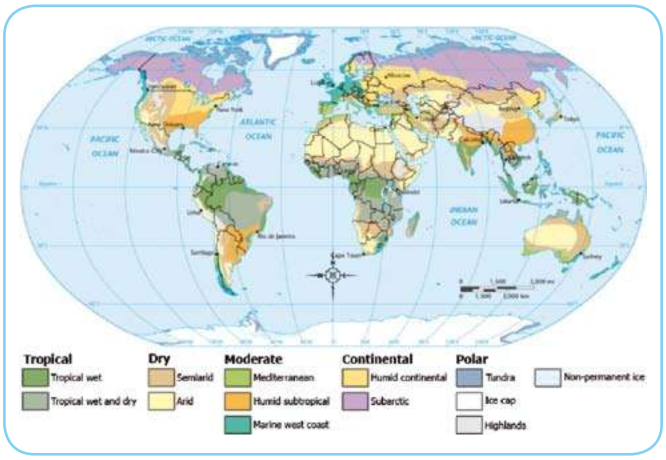
Three classifications for elevation are given in Table 4: low (< 100 m, i.e., near sea-level), moderate (100-2000 m) and high (> 2000 m). Low-elevation urban conurbations near sea-level are very susceptible to flooding and salinization because they are often located near the ocean or tidal rivers. High-elevation urban conurbations are also subject to salinization because they are invariably arid. Moderate and high-elevation conurbations are also susceptible to loss of supply through more rapid melting of glaciers.

The classifications for climate are taken from the climatic zones outlined in Figure 4. Climate plays a significant role in determining the presence or absence of water supply and quality problems. Climatic zones subject to severe rainfall or snow melt often face flooding problems. Many of these areas can also experience drought due to climate change or natural phenomena (e.g., El Niño). Arid and semi-arid zones can experience loss of supply or commonly, salinization, due to high rates of evaporation and concentration of salts in sols and surface and ground waters.

Infectious agents such as bacteria and viruses are frequently found in water bodies in tropical and subtropical zones.

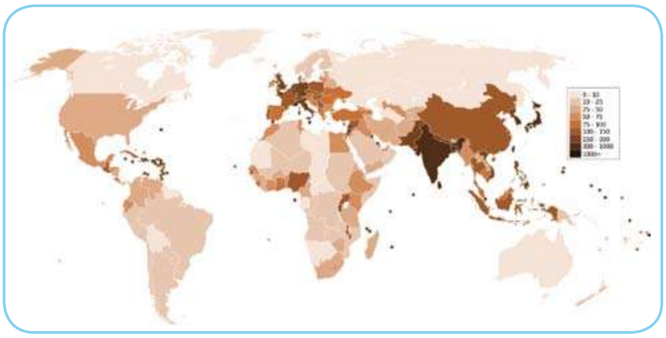
The underlying geology of urban conurbations plays a significant role in their ensuing water supply and quality. Naturally high 'background' concentrations of elements such as arsenic and fluoride can result in contamination of groundwater supplies, as is the case in south-east Asia and many other parts of the world affected by natural arsenic pollution. Urban centers in earthquake or volcanic zones can be affected by quakes or eruptions, with their ensuing problems with water quality and supply outlined in Table 2. Geothermal activity can cause degradation of pipes and other water infrastructure, and the surrounding surface and ground waters are often hot, as well as salt-, metal-and metalloid-rich.

Figure 4: World Climatic Classifications



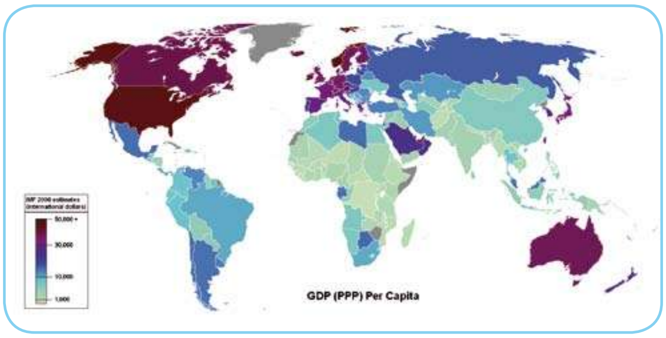
Note: From http://en.wikipedia.org/wiki/ File:ClimateMap_World.png, used under the GNU Free Documentation License. (http://commons.wikimedia.org/wiki/ GNU_Free_Documentation_License).

Figure 5: Countries by population density



Note: Numbers on the legend are in people per km2, and all countries smaller than 20,000 km2 are represented by a dot. From http://en.wikipedia.org/wiki/File:Countries_by_ population_density.svg, public domain figure.

Figure 6: World map showing countries by nominal GDP per capita in 2008



Note: Created using estimates as of April 2009 International Monetary Fund World Economic Outlook Database April 2009. Created June 2009. From http://en.wikipedia.org/wiki/File:GDP_PPP_Per_Capita_ IMF_2008.png.

Population density also plays a major role in determining the supply and quality of water. Population density is considered the equivalent of building density, since it is assumed that the two are directly correlated. Two divisions are considered for Table 4: densities greater than 300 km^2 and those less than 300 km^2. The map in Figure 5 is used to make these subdivisions, and it can be seen that densities are greatest in south-east Asia, western Europe and parts of the Caribbean. Urban areas of both high and low population density can experience overuse and insufficient or degrading infrastructure (Table 4). Water supplies in high density areas can also have excessive concentrations of nutrients, due to urban agriculture or gardening. These high-density areas are also more prone to flooding that low-density areas, due to their higher density of built structures that lead to excessive run-off and high flood magnitudes (Figure 3).

Gross domestic product per capita is an important factor relating to water supply and quality. For Table 3, this factor is divided into three: GDP > \$50,000, GDP \$1,000-\$50,000 and GDP < \$1,000 (US dollars). The map in Figure 6 is used to separate countries and their urban conurbations. Urban conurbations with high and moderate GDP, such as those in North America Russia, Australia and parts of Central and South America, share the potential water supply problems of overuse and insufficient or degrading infrastructure. Low-GDP conurbations also potentially have these problems, but also face water quality issues relating to infectious agents (bacterial or viral diseases) and organic contaminants. It should be noted that the GDP values are averages, so countries in Figure 6 that have high or moderate GDP have urban centers that can include slum areas (e.g., large cities in the US), which face the same problems as low-GDP areas.

Table 4 shows that industrial activities in urban centers can cause future problems with water supply and quality. All of the industries shown in the table (agriculture, chemical, refining, manufacturing, energy) can cause overuse, degradation of water infrastructure, and contamination. The type of contamination is industry-dependent: agriculture, for example, can result in excessive discharge of organics or nutrients, while the energy industry can release excessive heat and sediments.

The general table (Table 4) reveals some interesting trends. The two most common problems are related to water supply: overuse and insufficient or degrading infrastructure, and these are present despite differences in population (building) density, GDP and industry. Physical factors relating to proximity to surface water, elevation and climate do not impact on these two problems. Geological factors including proximity to earthquake-prone, volcanic and geothermal areas impact on infrastructure but not water overuse. The water supply problems of flooding, drought and loss of supply are almost exclusively related to physical factors of proximity to surface water, elevation, climate and geology, but population (building) density does play a role in flood risk.

Water quality problems do not show the same trends as those of water supply, being spread over both physical and human geographic factors in Table 4. Apart from agriculture, salinization is mainly a physical geography issue, especially near oceans and in arid, volcanic or geothermal zones. Proximity to surface water, elevation and climate do not play major roles in contamination of water with organics, metals, metalloids, nutrients, heat or sediments (except for riverine zones), but geology does influence all of these, particularly in areas with high natural background element concentrations or volcanic or geothermal activity. Much contamination of water occurs due to industrial activity.

Table 4 can be used for all urban conurbations, whether or not they are large cities or small towns. The last column of the table is designed for adding potential problems for a particular urban conurbation. Table 5 presents an example of this for London, UK. London is located on the River Thames with an elevation of < 100 m, and thus is potentially subject to future flooding in periods of high flow and salinization in periods of extreme low flow. These two potential problems give scores of two in both the proximity to surface water and elevation categories. London's climate, according to the divisions in Figure 4 and Table 5, is marine west coast, potentially leading to flooding problems, and giving an addition one to the score. The city has no 'abnormal' geological conditions, and thus no additional future problem score in this area. It does have a high population density, giving an additional score of five relating to future problems of overuse, degrading infrastructure and contamination with nutrients and heat due to the urban 'heat island' effect. The high average GDP per capita of > $50,000 can lead to future problems of overuse and insufficient or degrading infrastructure, and gives an addition two points to the score. The total score for London is 12, which will be compared to other cities described in the case studies in Section 3 of this report.

It should be noted that the total score, although numerical, is qualitative, and therefore should be used as a guideline only. The assessment of potential future problems is carried out using average conditions for the different geographic categories. There are undoubtedly small-scale variations within urban areas (such as different GDPs for slum versus wealthier areas) that would increase or decrease the total score.

To summarise, both natural (geographic location, elevation above sea-level, climate, geology) and man-made factors (population density, GDP, industry) impact on water supply and quality in urban areas. Although in Table 4 each point is weighted equally in the overall score, the relative importance of the crisis drivers to water supply and quality will vary according to which driver is active at a particular time. This is illustrated in the future scenario case studies in Section 3; the volcanic eruption scenario for Mexico City, described in Section 3.4., is an infrequent, acute event that would have very serious effects on water supply and quality for slum dwellers in this city. By contrast, urbanization and the pressures of increasing population (themes common to all five case studies) are chronic problems that build up over time. It is perhaps these chronic problems, particularly population growth, that are the most serious and thus, the most important to solve.

Table 4: General water supply and quality urban zone prediction matrix

General Table	WATER SUPPLY PROBLEMS					WATER QUALITY PROBLEMS							
GEOGRAPHIC FACTOR	Flooding	Drought	Overuse	Loss of supply	Insufficient or degrading infrastructure	Salinization	Infectious agents	Organics	Metals and metalloids	Nutrients	Thermal	Sediments	Total potential problems
PROXIMITY TO SURFACE WATER													
Ocean	×					×							
River	×					×						×	
ELEVATION ABOVE SEA-LEVEL													
< 100 m	×					×							
100 m – 2000 m				×									
> 2000 m				×		×							
CLIMATE													
Tropical wet	×						×						
Tropical wet and dry	×	×					×						
Semiarid		×				×							
Arid		×		×		×							
Mediterranean	×	×				×							
Humid subtropical	×	×					×						
Marine west coast	×												
Humid continental	×												
Subarctic	×	×											
Tundra		×											
GEOLOGY													
Naturally high background element concentrations						×			×	×			
Earthquake zone	×			×	×		×						
Volcanic zone	×			×	×	×			×		×		
Geothermal					×	×			×		×		
URBAN													
Pop Dens >300 km^2	×		×		×					×	×		
Pop Dens < 300 km^2			×		×								
GDP >$50,000			×		×								
GDP $1,000-10,000			×		×								
GDP < $1,000			×		×		×	×					
INDUSTRY													
Agricultural			×		×			×		×			
Chemical			×		×			×	×	×			
Refining			×		×			×	×				
Manufacturing			×		×				×				
Energy			×		×						×	×	
												TOTAL	

Table 5: Water supply and quality urban zone prediction matrix for London, UK

London, UK	WATER SUPPLY PROBLEMS					WATER QUALITY PROBLEMS							
GEOGRAPHIC FACTOR	Flooding	Drought	Overuse	Loss of supply	Insufficient or degrading infrastructure	Salinization	Infectious agents	Organics	Metals and metalloids	Nutrients	Thermal	Sediments	Total potential problems
PROXIMITY TO SURFACE WATER													
Ocean	×					×							
River	×					×						×	2
ELEVATION ABOVE SEA-LEVEL													
< 100 m	×					×							2
100 m – 2000 m				×									
> 2000 m				×		×							
CLIMATE													
Tropical wet	×						×						
Tropical wet and dry	×	×					×						
Semiarid		×				×							
Arid		×		×		×							
Mediterranean	×	×				×							
Humid subtropical	×	×					×						
Marine west coast	×												1
Humid continental	×												
Subarctic	×	×											
Tundra		×											
GEOLOGY													
Naturally high background element concentrations						×			×	×			
Earthquake zone	×			×	×		×						
Volcanic zone	×			×	×	×			×		×		
Geothermal					×	×			×		×		
URBAN													
Pop Dens >300 km^2	×		×		×					×	×		5
Pop Dens < 300 km^2			×		×								
GDP >$50,000			×		×								2
GDP $1,000-10,000			×		×								
GDP < $1,000			×		×		×	×					
INDUSTRY													
Agricultural			×		×			×		×			
Chemical			×		×			×	×	×			
Refining			×		×			×	×				
Manufacturing			×		×				×				
Energy			×		×						×	×	
												TOTAL	12

Table 6: Water supply and quality urban zone prediction matrix for Dhaka, Bangladesh

Dhaka, Bangladesh	WATER SUPPLY PROBLEMS					WATER QUALITY PROBLEMS							
GEOGRAPHIC FACTOR	Flooding	Drought	Overuse	Loss of supply	Insufficient or degrading infrastructure	Salinization	Infectious agents	Organics	Metals and metalloids	Nutrients	Thermal	Sediments	Total potential problems
PROXIMITY TO SURFACE WATER													
Ocean	×					×							2
River	×					×						×	
ELEVATION ABOVE SEA-LEVEL													
< 100 m	×					×							2
100 m – 2000 m				×									
> 2000 m				×		×							
CLIMATE													
Tropical wet	×						×						2
Tropical wet and dry	×	×					×						
Semiarid		×				×							
Arid		×		×		×							
Mediterranean	×	×				×							
Humid subtropical	×	×					×						
Marine west coast	×												
Humid continental	×												
Subarctic	×	×											
Tundra		×											
GEOLOGY													
Naturally high background element concentrations						×			×	×			3
Earthquake zone	×			×	×		×						
Volcanic zone	×			×	×	×			×		×		
Geothermal					×	×			×		×		
URBAN													
Pop Dens >300 km^2	×		×		×					×	×		5
Pop Dens < 300 km^2			×		×								
GDP >$50,000			×		×								
GDP $1,000-10,000			×		×								
GDP < $1,000			×		×		×	×					4
INDUSTRY													
Agricultural			×		×			×		×			4
Chemical			×		×			×	×	×			5
Refining			×		×			×	×				
Manufacturing			×		×				×				3
Energy			×		×						×	×	
												TOTAL	30

Table 7: Water supply and quality urban zone prediction matrix for Guiyu, China

Guiyu, China	WATER SUPPLY PROBLEMS					WATER QUALITY PROBLEMS							
GEOGRAPHIC FACTOR	Flooding	Drought	Overuse	Loss of supply	Insufficient or degrading infrastructure	Salinization	Infectious agents	Organics	Metals and metalloids	Nutrients	Thermal	Sediments	Total potential problems
PROXIMITY TO SURFACE WATER													
Ocean	×					×							
River	×					×						×	3
ELEVATION ABOVE SEA-LEVEL													
< 100 m	×					×							2
100 m – 2000 m				×									
> 2000 m				×		×							
CLIMATE													
Tropical wet	×						×						
Tropical wet and dry	×	×					×						
Semiarid		×				×							
Arid		×		×		×							
Mediterranean	×	×				×							
Humid subtropical	×	×					×						3
Marine west coast	×												
Humid continental	×												
Subarctic	×	×											
Tundra		×											
GEOLOGY													
Naturally high background element concentrations						×			×	×			
Earthquake zone	×			×	×		×						
Volcanic zone	×			×	×	×			×		×		
Geothermal					×	×			×		×		
URBAN													
Pop Dens >300 km^2	×		×		×					×	×		
Pop Dens < 300 km^2			×		×								2
GDP >$50,000			×		×								
GDP $1,000-10,000			×		×								2
GDP < $1,000			×		×		×	×					
INDUSTRY													
Agricultural			×		×			×		×			
Chemical			×		×			×	×	×			5
Refining			×		×			×	×				4
Manufacturing			×		×				×				
Energy			×		×						×	×	
												TOTAL	21

Table 8: Water supply and quality urban zone prediction matrix for Mexico City, Mexico

Mexico City, Mexico	WATER SUPPLY PROBLEMS					WATER QUALITY PROBLEMS							
GEOGRAPHIC FACTOR	Flooding	Drought	Overuse	Loss of supply	Insufficient or degrading infrastructure	Salinization	Infectious agents	Organics	Metals and metalloids	Nutrients	Thermal	Sediments	Total potential problems
PROXIMITY TO SURFACE WATER													
Ocean	×					×							
River	×					×						×	
ELEVATION ABOVE SEA-LEVEL													
< 100 m	×					×							
100 m – 2000 m				×									
> 2000 m				×		×							2
CLIMATE													
Tropical wet	×						×						
Tropical wet and dry	×	×					×						
Semiarid		×				×							2
Arid		×		×		×							
Mediterranean	×	×				×							
Humid subtropical	×	×					×						
Marine west coast	×												
Humid continental	×												
Subarctic	×	×											
Tundra		×											
GEOLOGY													
Naturally high background element concentrations						×			×	×			
Earthquake zone	×			×	×		×						4
Volcanic zone	×			×	×	×			×		×		6
Geothermal					×	×			×		×		
URBAN													
Pop Dens >300 km^2	×		×		×					×	×		5
Pop Dens < 300 km^2			×		×								
GDP >$50,000			×		×								2
GDP $1,000-10,000			×		×								
GDP < $1,000			×		×		×	×					
INDUSTRY													
Agricultural			×		×			×		×			
Chemical			×		×			×	×	×			
Refining			×		×			×	×				4
Manufacturing			×		×				×				4
Energy			×		×						×	×	
												TOTAL	29

Table 9: Water supply and quality urban zone prediction matrix for Lagos, Nigeria

Lagos, Nigeria	WATER SUPPLY PROBLEMS					WATER QUALITY PROBLEMS							
GEOGRAPHIC FACTOR	Flooding	Drought	Overuse	Loss of supply	Insufficient or degrading infrastructure	Salinization	Infectious agents	Organics	Metals and metalloids	Nutrients	Thermal	Sediments	Total potential problems
PROXIMITY TO SURFACE WATER													
Ocean	×					×							2
River	×					×						×	
ELEVATION ABOVE SEA-LEVEL													
< 100 m	×					×							2
100 m – 2000 m				×									
> 2000 m				×		×							
CLIMATE													
Tropical wet	×						×						
Tropical wet and dry	×	×					×						3
Semiarid		×				×							
Arid		×		×		×							
Mediterranean	×	×				×							
Humid subtropical	×	×					×						
Marine west coast	×												
Humid continental	×												
Subarctic	×	×											
Tundra		×											
GEOLOGY													
Naturally high background element concentrations						×			×	×			
Earthquake zone	×			×	×		×						
Volcanic zone	×			×	×	×			×		×		
Geothermal					×	×			×		×		
URBAN													
Pop Dens >300 km^2	×		×		×					×	×		5
Pop Dens < 300 km^2			×		×								
GDP >$50,000			×		×								
GDP $1,000-10,000			×		×								
GDP < $1,000			×		×		×	×					4
INDUSTRY													
Agricultural			×		×			×		×			
Chemical			×		×			×	×	×			
Refining			×		×			×	×				4
Manufacturing			×		×				×				4
Energy			×		×						×	×	
												TOTAL	24

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Humanitarian Crisis Drivers of the Future

This report is one of a series of three. The other two reports focus on pandemics and the Third Pole. A synthesis report is also available. For more details please contact the Humanitarian Futures Programme.