THE INTERNET OF THINGS: OPPORTUNITIES FOR WATER, SANITATION AND HYGIENE (WASH) MANAGEMENT

Dr Louis Coetzee and Prof Paula Kotzé

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The Internet of Things: Opportunities for Water, Sanitation and Hygiene (WASH) Management

Report to the
Water Research Commission

by

Dr Louis Coetzee and Prof Paula Kotzé
Council of Scientific and Industrial Research, Meraka Institute

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EXECUTIVE SUMMARY

BACKGROUND

The human rights to water, sanitation and hygiene, collectively known as WASH, are guaranteed under national and international law as components of the right to an adequate standard of living. The legislative framework for water supply and sanitation services, water resource management and water are set by the Constitution of the Republic of South Africa and mandated under the Water Services Act of 1997 and the National Water Act of 1998. Water is recognised as a strategic resource in ensuring a minimum standard of living for all people in South Africa's National Development Plan (NDP). In relation to hygiene, the National Sanitation Policy 2016 states that all public and private institutions are responsible to provide sanitation services, including hand washing facilities, hygiene and end-user education. The NDP envisages that all South African people will have affordable, and reliable access to hygienic sanitation by 2030. Water, sanitation and hygiene are inextricably linked to a range of other human rights, including the rights to life, health, education and housing. The South African position on WASH is not clear cut as there is no integrated WASH sector in South Africa. The responsibilities for services delivery are distributed between national and provincial departments, e.g. Departments of Water and Sanitation, Cooperative Governance and Traditional Affairs, Human Settlements, Health, Basic Education, Social Development, Environmental Affairs and Public Works, with mandates between these departments often overlapping.

It is estimated that 2.6 million households do not have access to safe drinking water, while 400 000 households do not have a toilet facility in South Africa. Schools are severely impacted with almost a third of schools (29%) only having an unimproved pit latrine or no toilet facilities [UNICEF, 2017]. These circumstances lead to significant proportions of young children and vulnerable individuals to die of preventable illnesses. The high prevalence of water and hygiene-related illnesses, such as diarrhoea and intestinal worms, further contributes to malnutrition and poor school attendance, which could result in cognitive impairment and reduced learning outcomes [Department of Health, 2015; UNICEF, 2017]. Access to adequate WASH services is therefore an important mechanism to address risks associated with the burden of disease of any country.

AIMS AND OBJECTIVES

The use of information and communications technologies (ICTs) has been posited as one way of addressing the burden of disease and improving quality of life for those most at risk. One of the new developments in ICT, the 'Internet of Things' (IoT), allows for the integration of digital and the physical worlds, resulting in the creation of new services that can be deployed for positive impact, also in the WASH context. Innovative IoT work, including technology development and applications, is being done in relation to WASH services in both the developed and developing world context. One example of using IoT in a WASH context is a system using accelerometers in water lever hand pumps [Thomson, Hope & Foster, 2012]. This system measures the utilisation and status of a hand pump, thus providing near-real time insight into the operational status of the device. This in turn allows for value-add such as faster response times for maintenance. However, there are very limited examples (and if at all) of IoT deployment providing WASH services in South Africa.

This report presents insights into the use of IoT in support of WASH services provision, monitoring and evaluation, regulation and enforcement. Specifically, the report focuses on framing the WASH context (nationally and internationally), define the concept of IoT, extract current applications of IoT in WASH and define future opportunities for IoT application in the WASH sector.

RESEARCH APPROACH

These insights regarding the possible use of IoT for WASH in South Africa are based on a limited scope literature review as guided by value chains (required services) for water, sanitation and hygiene. This analysis included criteria for each of the water, sanitation and hygiene sub-domains and the WASH sector collectively, diseases related to WASH, and international as well as South African data for the criteria and related diseases. The findings were combined with insight acquired on the IoT domain in general, both from literature and our past experience and learnings. Example case studies of the use of IoT in the WASH sector in developing countries and, where possible from (South) Africa, provided further background.

SUMMARY OF FINDINGS

The study found that there is limited use of IoT in the WASH domain in South Africa (and Africa). Currently the only use of IoT-related technology in South Africa is in the smart water management domain, which is mostly limited to measuring the amount of *improved water* use and payment thereof, primarily in metropolitan areas. No use is made of IoT to improve the livelihood and health of the majority of the South African population, and especially those depending on basic, limited or unimproved water resources, basic, limited or unimproved sanitation facilities, or basic or limited handwashing facilities. This finding was supported by both the literature review and the inputs received from the stakeholder's responses to the survey. Apart from the current focus on 'urban' applications of IoT in mainly the water sector, which is also necessary, there are therefore huge opportunities to investigate the use and benefits of IoT in WASH as an integrated and interlinked domain. Vast opportunities also exist for research to determine how IoT technologies can be used to improve the lives and health of the large proportion of the South African population that depend on WASH services that cannot be classified as safely managed, improved or advanced, and to develop suitable technologies to fit such environments.

CONCLUSIONS AND RECOMMENDATIONS

More detailed observations include the following:

- WASH is not seen as a single domain or sector in South Africa. This implies that data and insight over the whole WASH value chain are challenging. It further implies that executing a program using a transversal technology such as IoT will need to engage and get buy-in from a multitude of stakeholders.
- IoT has not matured to the point that where a common and broad understanding exists. As it is still evolving, different views exist. As these views differ, stakeholders need a converged view to implement a large scale IoT intervention.
- Technologies are rapidly evolving. In the near-future bespoke solutions will be replaced by "commercial-off-the-shelf" technologies. This will lower the entry barrier and ease the deployment of IoT solutions. Currently this is still a challenge and needs to be mitigated by developing low cost and localised to the South African domain solutions.
- IoT still has a relatively small footprint in South Africa. Quite often solutions are positioned for "smart resource management", most often in the energy domain.
- As a result of the small footprint, IoT skills are still not as widespread and common as to allow for easy deployment, and support and maintenance of solutions. However, this situation is changing rapidly with the awareness of IoT increasing substantially.
- Internationally, testbeds have been applied successfully to bridge the gap from lab to the real-world. A testbed typically is an open-experimental platform instantiated in a near-real world environment. It would be beneficial to create and support dedicated IoT for WASH testbeds. This generates opportunities to rapidly expand the application of IoT for WASH and to move research into the community domain.
- Of critical importance is that IoT and WASH interventions be community driven. Without community support and buy-in the intervention will be doomed to failure.
- Communities need to have the required transparency into the solution (and the usage of their data) as well as the trust in the systems, solution providers as well as governance models.

- Communities of practise in relation to application of IoT (in general, but more specifically in WASH) are not well established. Knowledge is constrained to silos, mostly aligned with a specific initiative or commercial products. Access to the knowledge is typically through academic peer review papers, or vendor web sites.
- The final responsibility in relation to consequences of having an IoT intervention in WASH need to be established and agreed upon before any real-world deployment. This will avoid a situation where potential negligence and failure are attributed to a party, but the party denying all responsibility.
- Business models to ensure sustainable interventions still need to be developed for the South African context. Using testbeds with community buy-in, experiments with different business models can be conducted.

The potential application of IoT for WASH is clear and need to be pursued. Bridging the gap from research into real-world solutions is difficult. As a way forward, it is recommended that a testbed is created in a community where several approaches applicable to all three dimensions of WASH are tested and validated.

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Reference Group	
Name	**Affiliation**
Dr N Kalebaila	Water Research Commission (Chairperson)
Prof B Twala	University of South Africa (formerly at University of Johannesburg)
Prof U Rivett	University of Cape Town
Ms R Munien	Water Research Commission
Mr C Mawing	Water Research Commission
Dr C Khene	Rhodes University
Prof R Malekian	University of Pretoria

Project Team	
Dr L Coetzee (Project Leader)	
Ms L Masango	
Prof P Kotze	
Mr A Selikow	

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CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

The human rights to water, sanitation and hygiene, collectively known as WASH, are guaranteed under national and international law as components of the right to an adequate standard of living. It is guaranteed nationally in the Constitution of the Republic of South Africa of 1996 [Constitutional Assembly, 2013] and internationally by the International Covenant on Economic, Social and Cultural Rights, as well as in many other human rights treaties [United Nations General Assembly, 1976]. The right of access to basic water supply and sanitation in South Africa is also addressed of in the Water Services Act of 1997 [Republic of South Africa, 1997b]. Moreover, water, sanitation and hygiene are inextricably linked to a range of other human rights, including the rights to life, health, education and housing [UNICEF; United Nations General Assembly, 1976, 2009, 2010, 2012]. Reporting on progress with the Millennium Development Goals (MDGs), UNICEF states that, in 2015, more than 660 million people lacked access to safe drinking water sources within a convenient distance from their habitation, 319 million of which lived in Sub-Saharan Africa. A total of 159 million people were dependent on surface water, of which 102 million lived in Sub-Saharan Africa [UNICEF and WHO, 2015]. By 2015, adequate sanitation facilities, for human excreta disposal in, or close to, peoples' habitation, were not available to 2.4 billion people, 695 million of which lived in Sub-Saharan Africa. This lack leaves the people at risk for water, sanitation and hygiene (WASH) related diseases. A 2010 study indicated that 801 thousand children worldwide died from diarrheal illnesses, mostly caused by unsafe water, poor sanitation and inadequate hygiene [Liu et al., 2012].

These risks are also applicable to South Africa, where a large number of people still do not have an acceptable toilet and cannot easily access safe water to drink or wash their hands. These circumstances lead to significant proportions of young children and vulnerable individuals to die of preventable illnesses. The high prevalence of water and hygiene-related illnesses, such as diarrhoea and intestinal worms, further contributes to malnutrition and poor school attendance, which could result in cognitive impairment and reduced learning outcomes [Department of Health, 2015; UNICEF, 2017]. Improvements related to drinking water, sanitation, hygiene, and water resource management could result in the reduction of almost 10% of the total burden of disease worldwide. In addition to diarrhoea, a significant proportion of the following diseases could be prevented if adequate water quality and quantity, sanitation facilities, hygiene behaviour, as well as water resource management interventions were implemented: malnutrition, intestinal nematode infections, lymphatic filariasis, trachoma, schistosomiasis and malaria [World Health Organization, 2017]. Access to adequate WASH services is therefore an important mechanism to address risks associated with the burden of disease of any country. However, factors such as inequality between the urban and rural dwellers and between the affluent and the poor, also affect the delivery of WASH services. As an example, in low-income countries almost half of the schools do not have access to adequate WASH services [Sahin, Abbot, & De Albuquerque, 2015]. The burden of disease therefore heavily affects the most vulnerable in our society. Addressing the need for adequate WASH services may go some way in alleviating the associated risks.

The use of information and communications technologies (ICTs) has been posited as one way of addressing the burden of disease and improving quality of life for those most at risk. One of the new developments in ICT, the 'Internet of Things' (IoT), allows for the integration of digital and the physical worlds resulting in the creation of new services that can be deployed for positive impact, also in the WASH context. IoT has been successfully applied in other domains, for example Smart Cities where use-cases related to resource management, quality of life, and improved service delivery have been addressed. The impact of IoT in addressing challenges related to domains such as cities has been shown. However, it is not known to what extent IoT can impact on other domains beyond those typically associated with a developed world context.

Innovative IoT work, including technology development and applications, is being done in relation to WASH services in both the developed and developing world context (see for example [Biggs, Garrity, LaSalle, A. Polomska, & Pepper, 2016; Coalition, 2016]). However, it is unknown to what extent (and if at all) IoT approaches to providing WASH services have been pursued in South Africa. A 2013 Water Research Commission (WRC) report [Champanis, Rivett, Gool, & Nyemba-Mudenda, 2013], on the potential for the use of information and communication technologies (ICTs) in the South African water sector, aimed to learn from the successes and failures of existing systems in domains related to water, in order to establish national research needs and to initiate an agenda for the development of a long-term strategy of the use of ICTs in the WASH sector in South Africa. The report found a paucity of literature related to the water sector. Although the study primarily focuses on the water sector, reference is made to the WASH sector in its recommendations. The study found that mobile phones have not been used to their extent in the WASH domain, but specifically only refer to mobile payments as alternative payment methods and smart water metering as possible future use examples. No mention is made of the use of IoT in the WASH domain in the report.

The South African Water Research Commission (WRC) tasked the Meraka Institute of the Council for Scientific and Industrial Research (CSIR) to compile a concise report on the use of the Internet of Things (IoT) in the water, sanitation and hygiene (WASH) domain. This report is the outcome of this task and addresses:

- A concept and context description of WASH services provision.
- A concept description on what IoT entails.
- Detail on current examples and potential opportunities for IoT for in the WASH sector.
- Challenges and possible future scenarios for the use of IoT in WASH.

This new report presents views regarding the possible use of IoT for WASH in South Africa based on a limited scope literature review. The views are informed by an analysis of literature related to the WASH domain nationally and internationally. This analysis includes criteria for each of the water, sanitation and hygiene sub-domains and the WASH sector collectively, diseases related to WASH, and international as well as South African data for the criteria and related diseases. The findings are combined with insight acquired on the IoT domain in general, both from literature and our experience and learnings. Example case studies of the use of IoT in the WASH sector in developing counties, and where possible from (South) Africa, provided further background. Using the analysis of the information gathered on IoT and the WASH sector in general, and the South African context in specific, recommendations are presented of how IoT can be utilised in South Africa to support the WASH sector. As IoT matures, new opportunities will come to the fore, but more extensive further research and a deeper insight would be required to identify the opportunities for the WASH sector and how to exploit those opportunities. This report is positioned to inform policy makers, improve decision-making, and influence the design, implementation and commissioning of IoT enabled WASH services.

1.2 AIMS AND OBJECTIVES

The objective of this report is to present insights into the use of IoT in support of WASH services provision, monitoring and evaluation, regulation and enforcement. Specifically, the report aims to frame the WASH context (nationally and internationally), define the concept of IoT, extract current applications of IoT in WASH and define future opportunities for IoT application in the WASH sector.

1.3 PROJECT APPROACH

A desktop study approach combined with inputs from a survey was used to collect data for the report. The desktop literature review focused on the criteria for WASH related services as set out in the [United Nations General Assembly, 2015], WASH value chains and role players, existing IoT technologies, trends and implementations, as well as existing case studies in the IoT or similar domains. The information from the literature reviews was augmented with inputs from a survey conducted amongst stakeholders from various WASH sectors. The survey aimed to determine the current perception stakeholders in the technical, research, industry and policy domains have of the WASH sector and the use of IoT in service delivery in the WASH sector and service delivery in general.

1.4 REPORT LAYOUT

- **Section 2** defines the WASH concept as used in this report. This is followed by an overview of the global WASH context. It covers the criteria set by the United Nations (UN) and its United Nations Children's Fund (UNICEF) programme for the WASH domain. South Africa, as member of the UN, also subscribes to these criteria. A summary of the international data for the criteria is also supplied. The global context section concludes with an overview of diseases related to the availability and use of WASH services, and an overview of the human behavioural factors that should be taken into account during any WASH interventions, specifically as it applies to low and middle-income countries, such as South Africa. The global context is followed with an overview of the WASH context in South Africa. The regulatory and strategic context of WASH services is introduced, followed by summaries of WASH data for South Africa, including both local and international data.
- **Section 3** provides an introduction to IoT, including the drivers, value and challenges of IoT, the typical application areas IoT and current and future trends in IoT.
- **Section 4** provides an overview of the WASH value chains applicable to the South African context, which is used to contextualise the examples in the next section.
- **Sections 4.1** and **4.2** address the use of IoT in the WASH sub-domains of water, sanitation and hygiene. **Section 4.3** also describes inputs received via a stakeholder survey.
- **Section 5** analyses the findings of the study by identifying societal and technology challenges and proposing some future scenarios of what IoT can bring to the WASH sector.

CHAPTER 2: WATER, SANITATION AND HYGIENE (WASH) SERVICES DELIVERY – MONITORING CRITERIA AND DATA

2.1 INTRODUCTION

The Constitution of the Republic of South Africa of 1996 and its seventeen Amendments [Constitutional Assembly, 2013], sets the rules for how government works. There are three distinctive, inter-related and inter-dependent (co-operative) spheres of government in South Africa:

- National government: Laws and policies are approved by Parliament which is made up of the National Assembly and the National Council of Provinces (NCOP). Cabinet of Ministers act as the executive committee of government and each Minister is the political head of a government department. Each government department is responsible for implementing the laws and policies decided on by Parliament or the Cabinet. The NCOP made up of representatives of provincial legislatures and local government and has to debate and vote on any law or policy that affects provincial or local government.

- Provincial government: The powers of the provincial governments are circumscribed by the national constitution, which limits them to certain listed ‘functional areas’, usually governed by a number of provincial departments, for example, agriculture, arts and culture, economic development, education, environmental affairs, finance, health, human settlements, local government, police or public safety, public works, roads and transport, social development, sport and recreation, tourism. The provincial Department of Local Government are responsible for co-ordination, monitoring and support of municipalities in each province.

- Local government (municipalities and metros): Must provide basic services (for example, water and sanitation, electricity, refuse removal, municipal health services, municipal public transport, municipal roads, firefighting, parks and recreation, regulation of childcare, etc.), promote development and the environment, encourage community participation, and respect. Promote and fulfil human rights,

Provincial or local government may not do anything that is against the laws or policies set down by national government. Provincial government gets most of its money from the national government through Treasury. Local government also gets grants and some loans through the Treasury. According to the Constitution of the Republic of South Africa [Constitutional Assembly, 2013], everyone has the right to have access to sufficient water and an environment that is not harmful to their health and wellbeing. As stated above, local government is tasked to promote a safe and healthy environment and is responsible for water and sanitation services related to drinkable (potable) water supply systems and domestic wastewater and sewage disposal systems.

The human rights to water, sanitation and hygiene are also guaranteed under international law as components of the right to an adequate standard of living guaranteed in the International Covenant on Economic, Social and Cultural Rights [United Nations General Assembly, 1976], as well as in many other human rights treaties. Moreover, water, sanitation and hygiene are inextricably linked to a range of other human rights, including the rights to life, health, education and housing [United Nations General Assembly, 2009, 2010, 2012].

2.2 WHAT IS WASH?

WASH is the collective term for the associated concepts of safe drinking water, safe sanitation and hygiene [UNICEF]. According to the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) [WHO and UNICEF, 2017a]:

- Drinking water services refers to the accessibility, availability and quality of the main source used by households for drinking, cooking, personal hygiene and other domestic uses.
- Sanitation is the hygienic means of promoting health through the prevention of human contact with waste as well as the treatment and disposal of waste. Sanitation services refer to management of excreta from the facilities used by individuals, through emptying and transport of excreta for treatment and eventual discharge or reuse. Sanitation can also refer to the maintenance of hygienic conditions through services such as wastewater disposal and garbage collection.
- Hygiene refers to the conditions and practices that help maintain health and prevent spread of disease including handwashing, menstrual hygiene management and food hygiene.

Due to their interdependent nature, these three core issues are grouped together to represent a growing sector, called WASH for short. While each issue can be considered a separate field of work, each of them is dependent on the presence of the other. For example, without clean water, basic hygiene practices are not possible, without toilets, water sources become contaminated, etc. [UNICEF]. Although the term WASH has been used in several South African studies in the past (for example, Champanis et al. [2013], [Wilkinson, du Toit, & Mashimbye, 2013]), the meaning of the term and its coverage have never been explicitly defined. This may lead to confusion as to what the term WASH implies and actually covers. This report addresses the WASH in a narrow context by limiting the study only to the WASH sector as it relates to the associated concepts of *safe drinking water*, *safe sanitation* and *hygiene* (with a specific reference to handwashing), as defined by the JMP [WHO and UNICEF, 2017a]. Other terms that have been used in South Africa in conjunction with WASH are, for example, water resources and ecosystems, water resources management, water services management, urban and rural water supply, bulk water treatment and distribution, wastewater management, etc. These wider issues related to WASH are not addressed in this report as such, also due to the fact that most of it has been published elsewhere (see for example, Department of Water Affairs [2015], [Water Research Commission, Department of Science and Technology, & Department of Water and Sanitation, 2015], [Department of Water Affairs and Forestry, 2003], [South African Water Research Commission, 2017], etc.).

2.3 GLOBAL WASH CONTEXT

This section provides an overview of the international perspective of what WASH is, and the criteria used to 'measure' the provision of WASH services.

2.3.1 Global WASH Criteria and Data

In September 2015, Member States of the United Nations adopted the 2030 Agenda for Sustainable Development [United Nations General Assembly, 2015], comprising 17 Sustainable Development Goals (SDGs) and 169 targets addressing social, economic and environmental aspects of development. The resolution seeks to end poverty, protect the planet and ensure prosperity for all. The SDGs follows on the Millennium Development Goals (MDGs) representing the targets for 2015. Concerning WASH services, Goal 6 is to "Ensure availability and sustainable management of water and sanitation for all" and includes targets addressing all aspects of the freshwater cycle (see Sub-Goals 6.1 to 6.6 in Table 2-1) and the means of implementation for achieving these development outcomes (see 6a and 6b in Table 2-1).

Table 2-1: Sustainable Development Goal 6 [United Nations General Assembly, 2015: 15]

Sub-Goal	Description of Sustainable Development Goal
6.1	By 2030, achieve universal and equitable access to safe and affordable drinking water for all
6.2	By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations
6.3	By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
6.5	By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
6.6	By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes
6.a	By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies
6.b	Support and strengthen the participation of local communities in improving water and sanitation management
1.4	By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance.
3.9	By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination
4a	Build and upgrade education facilities that are child, disability and gender sensitive and provide safe, non-violent, inclusive and effective learning environments for all

Other WASH related SDGs include Goals 1.4, 3.9 and 4a (see Table 2-1) [United Nations General Assembly, 2015; WHO and UNICEF, 2017b]. The WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) [WHO and UNICEF, 2017a] is the custodian of global data on drinking water, sanitation and hygiene (WASH). The JMP service ladders are used to benchmark and compare service levels across countries and have been updated and expanded to facilitate enhanced global monitoring of drinking water, sanitation and hygiene as specified in the SDGs [WHO and UNICEF, 2017b].

2.3.2 **WASH Cross-cutting Criteria**

The United Nations identified a number of cross-cutting criteria for good practices in the WASH sector [United Nations General Assembly, 2010]:

- *Non-discrimination*: In many countries around the world, people are discriminated against because of their colour, sex, language, ethnicity, nationality or other issues. In the WASH arena, discrimination can manifest itself in denied or restricted access to sanitation facilities and/or water sources. The non-discrimination criterion is aimed at highlighting and redressing these types of situations. Non-discrimination is at the heart of human rights law, and present in most human rights treaties and declarations.

- *Participation*: When sanitation and water are planned and implemented without sufficient participation of the beneficiaries, it can compromise the effectiveness of a project since it may not meet the beneficiaries' needs. Participation is also central human rights requirement and indivisible from the realization of all other human rights.
- *Accountability*: Clear lines of accountability should exist to assist responsible parties to know their obligations and help individuals to claim their rights. When interventions in the water and sanitation sectors are perceived as charity, people are offered services as passive beneficiaries with the hope to gain access to such sources, but do not have a sense of entitlement. When roles and responsibilities are not clearly defined, people may not know where to turn to when access to water and sanitation is non-existent or inadequate. Accountability is a key attribute of human rights law and a fundamental element for identifying good practices from a human rights perspective.
- *Impact*: Accountability mechanisms are important means for feedback on practices which require improvements. It relates to the impact criteria. Impact is essential for assuring meaningful interventions that can affect an improvement in peoples' lives. Any interventions should positively contribute to the realization of the human rights to water and sanitation.
- *Sustainability*: Sustainable development has been defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [United Nations General Assembly, 2010: p. 15], and has particular relevance to issues concerning water and sanitation. It relates to the longer-term positive and negative impacts of a particular practice. For example, water networks or other sources of water delivery may be built, but when capacity building to maintain such infrastructure is absent, the ongoing needs of the community in question will not be met. In addition, costs to maintaining water and sanitation facilities are frequently the reason for discontinued use, and the over-reliance on groundwater may result in the depletion of groundwater levels, leading to serious implications for the wider environment.

2.3.3 Criteria and Data for Water

The JMP's normative interpretation of terms used in *SDG target 6.1* is presented in Table 2-2.

Table 2-2: JMP Normative Interpretation of SDG target 6.1 [WHO and UNICEF, 2017b: 11]

SDG Language	Normative Interpretation
universal	Implies all exposures and settings, including households, schools, health facilities, workplaces and public spaces
and *equitable*	Implies progressive reduction and elimination of inequalities between population subgroups
access	Implies sufficient water to meet domestic needs is reliably available close to home
to *safe*	Safe drinking water is free from pathogens and elevated levels of toxic substances at all times
and *affordable*	Payment for services does not present a barrier to access or prevent people from meeting other basic human needs
drinking water	Water used for drinking, cooking, food preparation and personal hygiene
for all	Suitable for use by men, women, girls and boys of all ages, including people with disabilities

The JMPs approach to global monitoring aims to reflect this interpretation as closely as possible. The indicator selected for SDG target 6.1 is the 'proportion of population using safely managed *drinking water services*' [United Nations Economic and Social Council, 2016]. According to JMP a top priority for the SDG era will be to extend access to safely managed drinking water to those populations that remain unserved, by eliminating the use of surface water and unimproved sources that present the greatest risk to public health. JMP's estimate is that at the current rates of progress, more than one third of countries will not achieve universal access to an *improved* source of drinking water by 2030, with coverage of *safely managed* drinking water services an even greater challenge [WHO and UNICEF, 2017b]. Specific national programmes focused on increasing coverage of basic and safely managed drinking water services, in line with national strategies for sustainable development, need to be established to meet the targets [WHO and UNICEF, 2017b]. The 'for all' clause in SDG target 6.1, however, requires going beyond the household and also includes institutional settings and public spaces. JMP therefore developed separate services ladders for schools and healthcare facilities.

2.3.3.1 *General Drinking Water Ladder*

The JMP ladder for household drinking water services consists of five rungs: safely managed, basic, limited, unimproved and no service [WHO and UNICEF, 2017b]. It also classifies resources as safely managed, improved, unimproved and surface water. According to JMP, *improved drinking* water sources are those, which by nature of their design and construction, have the potential to deliver safe water. Improved drinking water resources sources include piped water, boreholes or tube wells, protected dug wells, protected springs and packaged or delivered water. In order to meet the criteria for a *safely managed* drinking water service, people must use improved source meeting three normative criteria [WHO and UNICEF, 2017a, 2017b]:

- Accessibility: Water should be accessible on premises.
- Availability: Water should be available when needed.
- Quality: The water supplied should be free from faecal and priority chemical contamination.

The JMP subdivides the population using *improved* sources into two groups according to the level of service provided [WHO and UNICEF, 2017a, 2017b]:

- Basic: If the improved source does not meet any one of above normative criteria, but a round trip to collect water takes 30 minutes or less, including queuing time, it will be classified as a basic drinking water service.
- Limited: If a round trip for water collection from an improved source exceeds 30 minutes, including queueing time, it will be categorised as a limited service.

Unimproved water resources refers to water collected from sources such as unprotected dug wells or springs [WHO and UNICEF, 2017a]. The *no service* level refers to the use of surface water refers to drinking water collected directly from an unprotected well or spring, and surface water (e.g. lake, river, stream, pond, canals, irrigation ditches) or any other source where water is not protected from the outside environment a river, dam, lake, stream or irrigation canal [UNICEF and WHO, 2016; WHO and UNICEF, 2017a].

2.3.3.2 *Drinking Water Ladder for Schools*

SDG target 4a includes an explicit reference to drinking water in *schools*. Countries are expected to report, among other things, on the proportion of schools with access to *basic drinking water* as a key element of a safe, non-violent, inclusive and effective learning environment. To address this, the JMP has developed new service ladders for monitoring WASH services in schools and healthcare facilities, and other settings once data become available [WHO and UNICEF, 2017b]. These service levels are advanced, basic, limited and no service, as defined in Table 2-3. The JMP target is of *basic* services for all schools, recognising that some countries may wish to specify higher targets. The SDG target indicator is the proportion of primary and secondary schools with *basic* drinking water, i.e. water from an *improved* source *available* at the school. The actual source does not have to be located on the school premises, as long as the water is available at the school, for example through storage tanks. If the water source is located at the school but the water is not available due to malfunction or service disruption, the school world be classified as having a *limited service*

Table 2-3: JMP service ladder for drinking water in schools [UNICEF and WHO, 2016; WHO and UNICEF, 2017b: 14]

Service Level	Definition
Advanced service	To be defined at national level (e.g. water is available when needed, accessible to all, free from faecal and prior faecal and priority chemical contamination based on water quality testing, etc.)
Basic service	Water from an improved source is available at the school
Limited service	There is an improved source, but water is not available at the time of survey
No service	No water source or unimproved source (unprotected well/spring, surface water source)

2.3.3.3 *Water Ladder for Healthcare Facilities*

Concerning *healthcare facilities*, access to water is critical for ensuring quality care for all, including vulnerable populations such as immunocompromised persons, expectant mothers and infants. In contrast to the ladder for school, which focuses on drinking water, the JMP ladder for healthcare facilities refers to general water supply and is not limited to drinking water. The reason for this is the importance of water for many purposes in healthcare facilities [WHO and UNICEF, 2017b]. The ladder for healthcare facilities is presented in Table 2-4. The SDG target indicator is the proportion of healthcare facilities with *basic* water supply, i.e. water from an *improved* source *available* on the healthcare facility premises.

Table 2-4: JMP service ladder for drinking water in healthcare facilities [WHO and UNICEF, 2017b: 15]

Service Level	Definition
Advanced service	To be defined at national level (e.g. water is available when needed, accessible to all, free from contamination, etc.)
Basic service	Water from an improved source is available at the premises
Limited service	There is an improved source, but water is not on premises or the water is not available
No service	No water source or an unimproved source

2.3.3.4 *Normative Criteria for Safely Managed Water Services*

See [United Nations General Assembly, 2010; WHO and UNICEF, 2017b].

2.3.3.4.1 Accessibility

Accessibility is a criterion for both *basic* and *safely managed* drinking water services. Water facilities must be physically accessible for everyone within each household or the immediate vicinity thereof, health or educational institution, public institutions and places, and the workplace [United Nations General Assembly, 2009, 2010]. The distance to the water facility should be in reach of every household, bearing in mind the special needs of certain groups and individuals. Often, people's security is threatened on their way to or while collecting water [United Nations General Assembly, 2010]. The path leading to the facility, and the facility or water source itself, should be safe and convenient for all users, including children, older people, persons with disabilities, women, including pregnant women, and chronically ill people. This may include features such as ramps or age-appropriate handrails for people with disabilities, interventions to bring water points closer to the home, the mobilization of community groups to ensure safety in and around water facilities, among many others. The tap should be reachable from a seated position, and it should be possible to open/close the water source/dispenser with minimal effort with one closed fist or feet, even by the smallest children [UNICEF and WHO, 2016; United Nations General Assembly, 2010].

The JMP will use a travel time indicator for accessibility, information that is routinely collected in national household surveys and censuses in many countries [WHO and UNICEF, 2017b]. Drinking water sources located on premises are not limited to piped water but can include a wide range of improved and unimproved source types. In Vietnam, for example, a large proportion of unprotected wells and springs are located on premises and could potentially be upgraded to improved facilities at relatively low cost. However, improved drinking water sources are more likely to be on premises than unimproved sources. When drinking water sources are not located on premises, households must spend time and energy collecting water. Typically, respondents are asked in JMP surveys to estimate the amount of time required to travel to the water source, queue if necessary, fill containers, and return to the household. While self-reported journey times are not always precise, they nevertheless provide a useful indicator of the relative time burden of water collection [WHO and UNICEF, 2017b].

Past statistics indicate that collecting water from unimproved drinking water sources is more likely to take over 30 minutes [WHO and UNICEF, 2017b]. According to the UN, the distance to the sanitation facility or water source should be in reach of every household, bearing in mind the special needs of certain groups and individuals [United Nations General Assembly, 2010]. In addition, the burden of water collection is far from evenly distributed among household members, as illustrated in Figure 2-1:

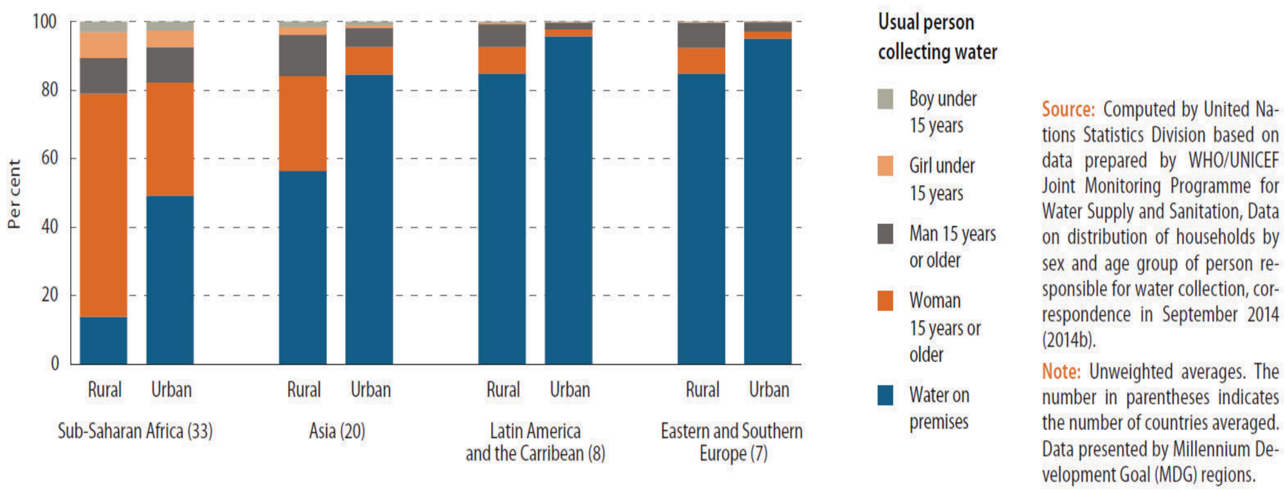


Figure 2-1: Distribution of households by person usually responsible for water collection, by region and by urban and rural areas, 2005-2013 [United Nations, 2015: p. 167]

The burden of hauling water falls disproportionately on women [United Nations, 2015; United Nations General Assembly, 2010; WHO and UNICEF, 2017b]. In 2015 it was found that in 53 out of 73 countries, over half of households with water off premises rely on women to collect water [United Nations, 2015]. In a few countries (e.g., Mongolia), men are primarily responsible, and in 14 countries, the burden also falls on children, with a boy or girl under 15 primarily responsible in at least 1 in 10 households [United Nations, 2015; WHO and UNICEF, 2017b]. Currently, sub-Saharan Africa has the largest share of the global population without access to improved drinking water, and alone accounts for nearly half of global population living without improved water sources [United Nations, 2015; WHO and UNICEF, 2017b].

2.3.3.4.2 Availability

Availability is another important criterion for assessing drinking water service levels. The human right to water specifies that water should be “available continuously and in a sufficient quantity to meet the requirements of drinking and personal hygiene, as well as of further personal and domestic uses, such as cooking and food preparation, dish and laundry washing and cleaning” [United Nations General Assembly, 2010: 6]. “Supply needs to be continuous enough to allow for the collection of sufficient amounts to satisfy all needs, without compromising the quality of water” [United Nations General Assembly, 2010: 6]. When the source of water is far away, the quantity of safe water that gets collected is less likely to be sufficient for minimum drinking needs or for good hygiene practices. It has been shown that the quantity of water that gets collected declines drastically if more than half an hour per trip is needed to collect the water [United Nations, 2015]. This is often the case in sub-Saharan Africa, where 29% of the population (37% in rural areas and 14% in urban areas) are at least 30 minutes or more away from an improved source of drinking water. The JMP focuses on the amount of time the water is available, rather than directly measuring the quantity of water delivered. The JMP also uses data on the number of hours of service per day, drawn from household surveys, regulators and utilities, and uses 12 hours per day as the global minimum benchmark for ‘available when needed’ [WHO and UNICEF, 2017b]. In 2015, an estimated 2.1 billion people worldwide lacked access to safely managed drinking water [WHO and UNICEF, 2017b], as illustrated in Figure 2-2. Of the 2.1 billion people, 27 million used basic services, 263 million used limited services, 423 million used unimproved sources and 159 million used surface water.

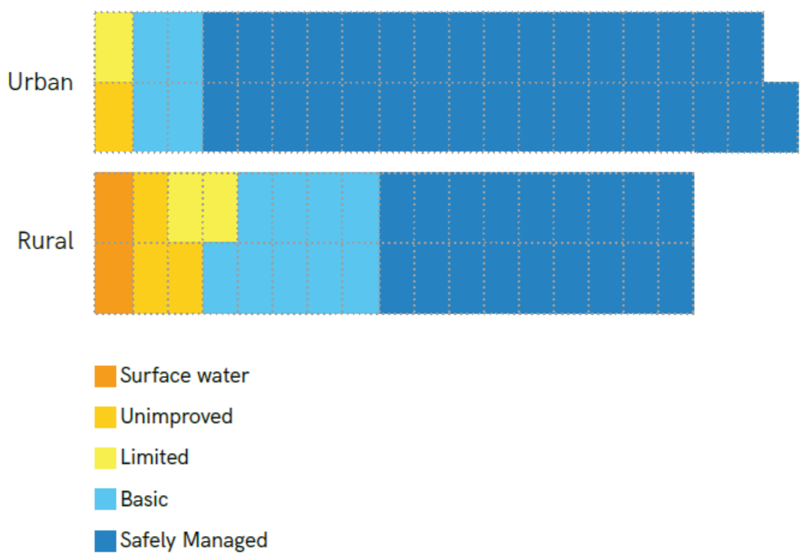


Figure 2-2: Number of people using different levels of drinking water services in 2015 in urban and rural areas (each block represents 100 million people) [WHO and UNICEF, 2017b: p. 24]

2.3.3.4.3 Quality

The issue of continuous water supply also links to quality, because household water storage bears risks in terms of water quality and health, and as a result people's capacity to go to school, work or otherwise participate in society [Gundry, Wright, & Conroy, 2004; United Nations General Assembly, 2010; WHO and The Network, 2007]. Water quality often deteriorates between collection and use [WHO and UNICEF, 2017b]. Water must be of such a quality that it does not pose a risk to human health [United Nations General Assembly, 2010]. The WHO defines safe drinking water as water that "does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages" [WHO, 2011: p. 1]. The lack of adequate drinking water, sanitation and hygiene are important environmental health risk factors with a tremendous impact on morbidity and mortality for both women and men. As noted above, many people do not have access to drinking water sources that are considered improved. In addition, not all sources considered improved provide safe, good quality water. For example, some of the drinking water sources considered 'improved' may not be adequately maintained and protected from outside contamination, including from naturally occurring elements such as arsenic and excessive fluoride in groundwater, pollution from industry and agriculture, inadequate sanitation, improper handling and household storage [United Nations General Assembly, 2010; WHO and UNICEF, 2017b]. The JMP recognizes that the best way to ensure water safety is through a holistic risk management approach such as water safety plans, but only a small number of countries have data on systems covered by a verified water safety plan [WHO and UNICEF, 2017b].

Water quality is in general affected by:

- *Microbial aspects*: Securing the microbial safety of drinking-water supplies is based on the use of multiple barriers, from catchment to consumer, to prevent the contamination of drinking water or to reduce contamination to levels not injurious to health. The greatest microbial risks are associated with ingestion of water that is contaminated with faeces from humans or animals (including birds). Faeces can be a source of pathogenic bacteria, viruses, protozoa and helminths. Faecally derived pathogens are the principal concerns in setting health-based targets for microbial safety and the verification of microbial water quality is likely to be based on the analysis of faecal indicator microorganisms [WHO, 2011]. Faecal contamination of drinking water is usually identified through the detection of the presence of indicator bacteria, such as Escherichia coli (*E. coli*) or thermo-tolerant coliforms, in a 100 mL sample and the point of delivery or collection. [WHO and UNICEF, 2017b]. This may differ from the quality of water at the point of consumption. A systematic review commissioned by the JMP, estimated that at least 1.8 billion people used drinking water sources that were contaminated with faecal indicator bacteria in 2012 [Bain et al., 2014].

Figure 2-3 indicates the proportion of contaminated supplies, by supply type, drawn from data the systematic review and related publications [Bain et al., 2014; WHO and UNICEF, 2017b]. The study also found that although improved sources are more likely to be free of microbial contamination, than unimproved sources, contamination is still widespread [Bain et al., 2014; WHO and UNICEF, 2017b]. However, despite a high access to improved water resources, the population using improved drinking water resources may be significantly lower. For example, Figure 2-4 shows data from four countries (Bangladesh, Congo, Ghana and Nepal) [WHO and UNICEF, 2017b]. While thee coverage of improved drinking water sources in these four countries ranges from 87% to 96%, the proportion of the population that actually uses improved drinking water sources free of faecal contamination is significantly lower. The reason for this is that water quality often deteriorates between collection and use. For the same four countries (Bangladesh, Congo, Ghana and Nepal), Figure 2-5 indicates the proportion of the population using water with no detectable *E. coli* at the point of collection and point of use.

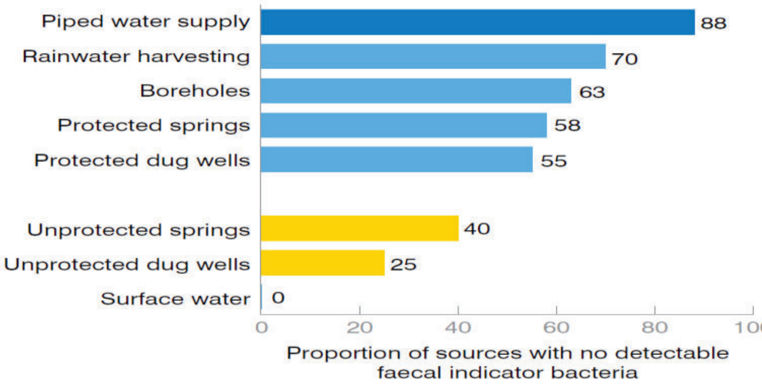


Figure 2-3: Proportion of population using water sources free of faecal contamination ([WHO and UNICEF, 2017b; P. 39] based on data from Bain et al. [2014])

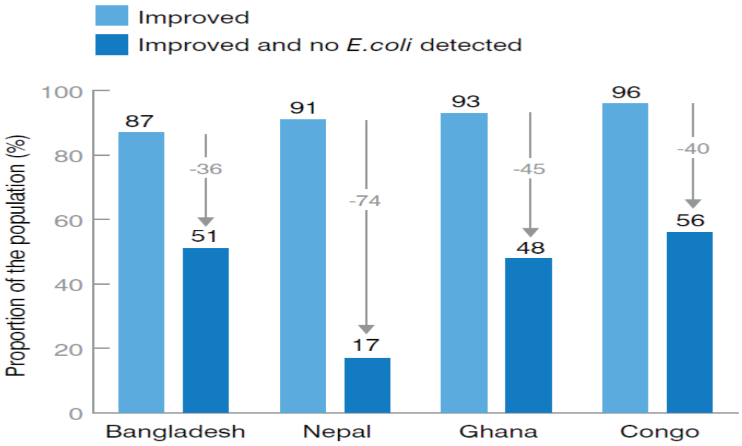


Figure 2-4: Coverage of improved drinking water sources and proportion of improved sources free from faecal contamination (%)[WHO and UNICEF, 2017b: p. 39]

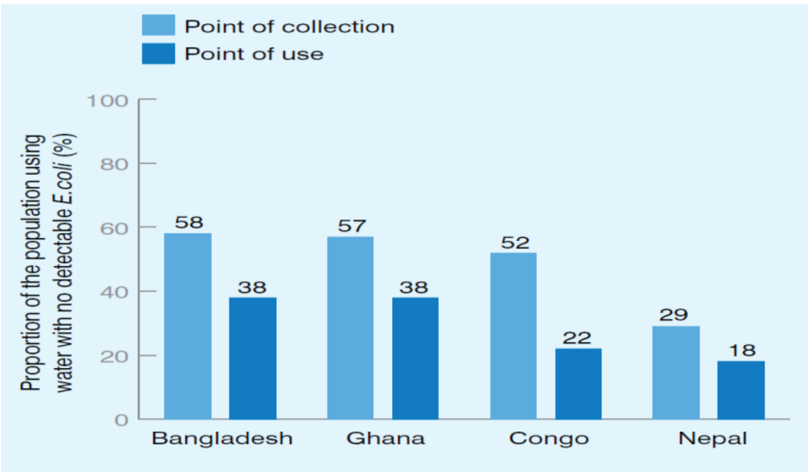


Figure 2-5: Proportion of the population using water with no detectable *E. coli* at the point of collection and point of use [WHO and UNICEF, 2017b; p. 40]

- *Chemical aspects*:
    - Chemical contamination: Although the great majority of evident water-related health problems are the result of microbial (bacterial, viral, protozoan or other biological) contamination, a considerable number of serious health concerns may occur as a result of the chemical contamination of drinking-water. The health concerns arise primarily from the ability of chemical constituents to cause adverse health effects after prolonged periods of exposure. There are few chemical constituents of water that can lead to health problems resulting from a single exposure, except through massive accidental contamination of a drinking-water supply. Assessment of the adequacy of the chemical quality of drinking-water relies on comparison of the results of water quality analysis with specified (national) guideline values [WHO, 2011].
    - Chemical disinfection: Disinfection is an effective barrier to many pathogens (especially bacteria) during drinking-water treatment and should be used for surface waters and for groundwater subject to faecal contamination. *Residual disinfection, for example filtration,* is used to provide a partial safeguard against low-level contamination and growth within the distribution system. The destruction of pathogenic microorganisms is, however, essential and very commonly involves the use of reactive chemical agents such as chlorine [WHO, 2011]. Other example of disinfection methods include boiling, solar disinfection(SODIS) and ultraviolet disinfection [UNICEF and WHO, 2016]. Although the chemical disinfection of a drinking-water supply that is faecally contaminated will reduce the overall risk of disease, it may not necessarily render the supply safe. For example, chlorine disinfection of drinking water has limitations against the protozoan pathogens some viruses. Disinfection efficacy may also be unsatisfactory against pathogens within flocs or particles, which protect them from the action of disinfectants [WHO, 2011].

- *Radiological aspects*:

  The health risks associated with the presence of naturally occurring radionuclides (radioactive substances) in drinking-water should also be taken into consideration. For example, some drinking water supplies sourced from groundwater may contain radon, a radioactive gas. However, the contribution of drinking water to total exposure to radionuclides is very small under normal circumstances, in comparison to risks from microorganisms and chemicals. Human-made radionuclides are often controllable at the point at which they enter the water supply. In contrast, naturally occurring radionuclides can potentially enter the water supply at any point, or at several points, prior to consumption. For this reason, naturally occurring radionuclides in drinking-water are often less amenable to control and therefore of greater concern [WHO, 2011].

- *Acceptability aspects*:

  These include taste, odour and appearance. Microbial, chemical and physical constituents of water may affect the appearance, odour or taste of the water. The consumer will evaluate the quality and acceptability of the water on the basis of these criteria through their senses. Although these constituents may have no direct health effects, water that is highly turbid, is highly coloured or has an objectionable taste or odour may be regarded by consumers as unsafe and rejected. Changes in the normal appearance, taste or odour of a drinking-water supply may signal changes in the quality of the raw water source or deficiencies in the treatment process and should be investigated [WHO, 2011]. But although water may have an acceptable taste, colour or odour, it may still be of unsafe quality if it does not meet the other quality criteria [United Nations General Assembly, 2010].

Microbial compliance alone does not guarantee safety though. To ensure safe drinking water, the WHO and UNICEF promote a Framework for Safe Drinking Water, as described in the WHO Guidelines for

Drinking Water Quality [WHO, 2011]. This framework comprises three key components [WHO, 2011; WHO and UNICEF, 2017b]:

- Health-based targets based on the evaluation of health risks: National standards should be established for contaminants that occur frequently at significant concentrations in a particular region or country and that have the greatest health impact. The WHO guideline values [WHO, 2011] for a range of contaminants can be used as a point of departure for developing national standards and regulations. National standards may be higher or lower than the WHO guideline values.
- Water safety plans (WSPs): Water safety plans (WSPs) are a systematic risk assessment and risk prevention approach encompassing all steps in the water supply system, from the catchment through to the consumer. By identifying the greatest risks and putting in place barriers, WSPs offer water suppliers a tool for managing the risks related to water and a framework to achieve water quality targets included in national standards and regulations. The principles of WSPs can be implemented for both large- and small-scale supplies. For example, simplified risk assessments with a stronger focus on risks related to transport and storage are more appropriate for community-managed systems. WSPs should comprise of
    - A system assessment to determine whether the drinking water supply as a whole (from source, through treatment, to the point of consumption) can deliver water of a quality that meets the health-based targets.
    - Operational monitoring of the control measures for the drinking water supply that is of particular importance in securing drinking water safety and quality.
    - Management plans documenting the system assessment and monitoring plans and describing actions to be taken in normal operation and incident conditions, including upgrade and improvement, documentation and communication.
- A system of independent surveillance that verifies the above are operating properly: In a WSP approach, surveillance of water quality at critical points in the system is important. It enables independent assurance that the WSP is appropriate, and that the chosen barriers are correctly implemented and effective in ensuring that water quality is meeting national standards. Findings from surveillance inform water safety policies and programmes and can serve as inputs to revisions to national standards and regulations.

2.3.3.4.4 Affordability

Water and sanitation facilities and services must be available for use at a price that is affordable to all people. In many places, the poorest, not connected to the public network for water and sanitation services, pay the most for water and sanitation services. People living in poverty sometimes have to buy water from informal private vendors, who can charge 10 to 20 times more than public utilities [Hutton, 2012; United Nations Development Programme, 2006]. However, even when water connections are available, people may find networked services unaffordable. Since water and sanitation are basic to survival, people may spend the extra money to acquire access, often at the expense of other human rights, such as food, housing, health services and education.[United Nations General Assembly, 2010]. When people are unable, for reasons beyond their control, to gain access to sanitation or water through their own means, Government is obliged to find solutions for ensuring this access. With respect to affordability, good practice examples might, for example, relate to the inclusion of water and sanitation services in social safety nets, microcredit programmes or revolving funds to help people afford the connection cost to the network, tariff structures with built-in cross-subsidies, policies regarding disconnections, or initiatives to monitor and regulate the price of water and sanitation [United Nations General Assembly, 2010: p. 9]. Special consideration should be given in cases of disconnection from the water supply due to a user’s inability to pay. Measures must be in place to ensure that such users are not deprived of access to safe water to meet their most basic personal and domestic needs, including sanitation needs when relying on water-borne sanitation [United Nations General Assembly, 2010]. Table 2-5 presents examples of the different types of costs associated with the provision of water services. Actual levels of expenditure vary depending on socioeconomic characteristics and the costs of WASH and other essential services, but Governments and international agencies have often set an affordability threshold of between 2 and 6% of total expenditure [Hutton, 2012]. Based on research by JMP and the World Bank, Figure 2-6 provides estimates of the percentage of household expenditure paid for WASH services, collated by the main source of drinking water in 52 countries, It indicates that households are more likely to pay for piped water than other sources [WHO and UNICEF, 2017b].

Table 2-5: Examples of different types of costs associated with water services [Hutton, 2012; WHO and UNICEF, 2017b: p. 20]

Service	Recurrent Costs	Capital Costs	Non-Financial Costs
Water	• Water tariff or user fee • Bottled or vendor water • Maintenance fees • Household water treatment costs	• Piped network connection • Water supply construction	• Collection time for water • Collection of 'fuel' for water treatment (boiling)

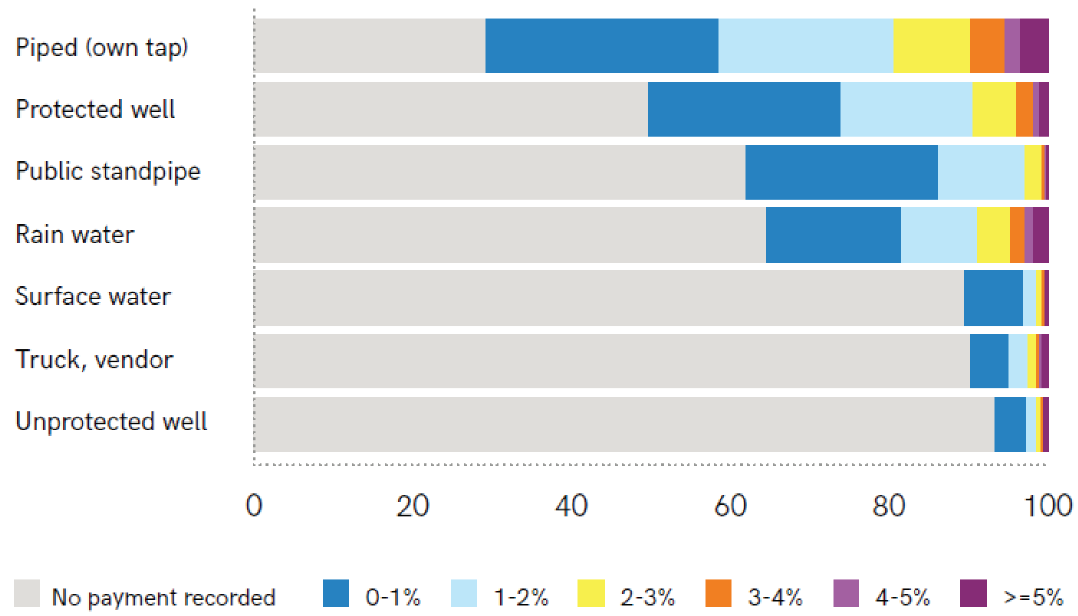


Figure 2-6: WASH expenditure as a percentage of household expenditure, by main source of drinking water based on data for 52 countries [WHO and UNICEF, 2017b: p. 20]

Based on the data for the same 52 countries, collated by region, Figure 2-7 indicates the proportion of total household expenditure spent on WASH services. In three SDG regions, over 10% of the population spends more than 2% of annual household expenditure on WASH services [WHO and UNICEF, 2017b].

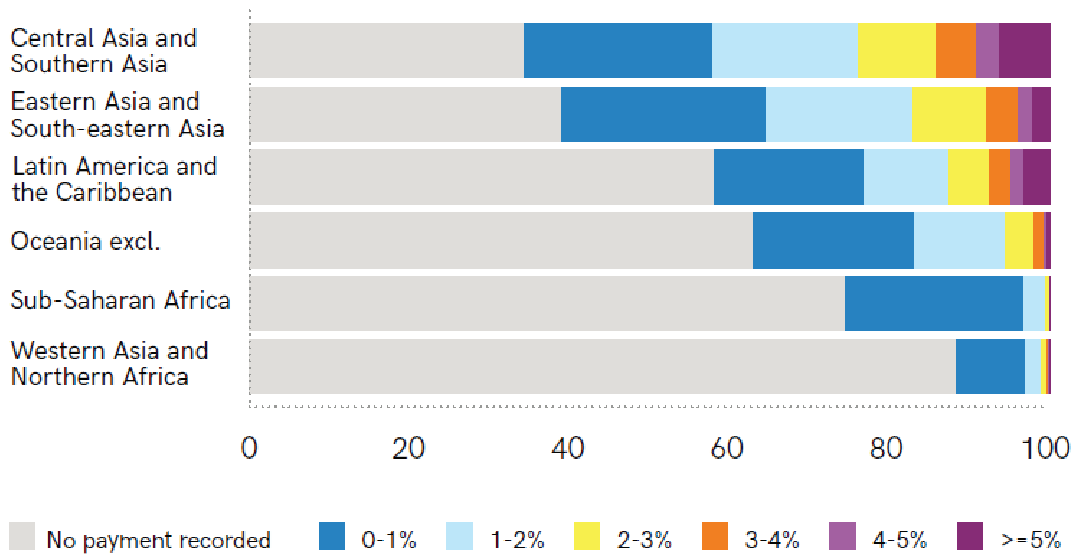


Figure 2-7: Proportion of total household expenditure on WASH services, by region based on data for 52 countries [WHO and UNICEF, 2017b: p. 20]

2.3.4 Criteria and Data for Sanitation

Consideration for water and sanitation goes hand in hand. Together with water, sanitation interventions are transformative and can be the entry point for broader societal change and facilitate the realisation of other human rights, such as health and education [United Nations General Assembly, 2009, 2012]. SDG 6.2 addresses sanitation. It states that by 2030 the goal is to “achieve access to adequate and equitable *sanitation* and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations” [United Nations General Assembly, 2015: 15]. The normative interpretation of SDG 6.2 [WHO and UNICEF, 2017c] is presented in Table 2-6. The MDG indicator ‘use of an improved sanitation facility’ focused on hygienic separation of excreta from human contact, but international consultations since 2011 established consensus on the need to go beyond access to a basic facility and address safe management of faecal waste along the sanitation chain[WHO and UNICEF, 2017c]. According to JMP, improved sanitation facilities are those designed to hygienically separate excreta from human contact [WHO and UNICEF, 2017a, 2017b]. For a sanitation service to be classified as *improved sanitation*, the facility must be designed to hygienically separate excreta from human contact. The new global SDG 6.2 indicator of ‘proportion of population using *safely managed sanitation* services’ [United Nations Economic and Social Council, 2016] is defined as use of an improved sanitation facility which are not shared with other households [WHO and UNICEF, 2017b, 2017c] and where the excreta produced is either:

- treated and disposed in situ,
- stored temporarily and then emptied and transported to treatment off-site, or
- transported through a sewer with wastewater and then treated off-site.

There is also a relationship between SDG 6.2 and 6.3 targets. SDG 6.3 states by 2030 the goal is to “improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally” [United Nations General Assembly, 2015: 15]. Among other things, the SDG target 6.3 thus aims to halve the proportion of untreated wastewater and to substantially increase recycling and safe reuse globally. SDG global indicators 6.3.1 ("Proportion of wastewater safely treated") and 6.2.1 ("Proportion of population using safely managed sanitation services") [United Nations Economic and Social Council, 2016]have many common elements, but also some key differences.

Table 2-6: Normative interpretation of SDG 6.2 [WHO and UNICEF, 2017c]

Target Language	Normative Interpretation
By 2030, achieve	
access	Implies facilities close to home that can be easily reached and used when needed
to *adequate*	Implies a system which hygienically separates excreta from human contact as well as safe reuse/treatment of excreta in situ, or safe transport and treatment off-site
and *equitable*	Implies progressive reduction and elimination of inequalities between population sub-groups
sanitation	Sanitation is the provision of facilities and services for safe management and disposal of human urine and faeces
and *hygiene*	Hygiene is the conditions and practices that help maintain health and prevent spread of disease including handwashing, menstrual hygiene management and food hygiene
for all	Suitable for use by men, women, girls and boys of all ages including people living with disabilities
end *open defecation*	Excreta of adults or children are: deposited (directly or after being covered by a layer of earth) in the bush, a field, a beach, or other open area; discharged directly into a drainage channel, river, sea, or other water body; or are wrapped in temporary material and discarded
paying special attention to the *needs of women and girls*	Implies reducing the burden of water collection and enabling women and girls to manage sanitation and hygiene needs with dignity. Special attention should be given to the needs of women and girls in 'high use' settings such as schools and workplaces, and 'high risk' settings such as health care facilities and detention centres
and *those in vulnerable situations*	Implies attention to specific WASH needs found in 'special cases' including refugee camps, detention centres, mass gatherings and pilgrimages

Most notably, target 6.2 considers only excreta generated by households, while target 6.3 additionally considers wastewater from economic activities (such as industrial wastes). While both indicators rely on data from household surveys and censuses to quantify the population using different types of sanitation facilities (sewer, septic, latrine or other), for target 6.2, excreta are considered to be safely managed if they receive at least some basic level of treatment (see section 3.1.3.2.3), while target 6.3 could consider actual efficiency of treatment, including compliance with environmental and public health effluent standards relevant for disposal or reuse, where data are available [WHO and UNICEF, 2017b].

2.3.4.1 *Sanitation Ladder*

The JMP service ladder for sanitation for households is presented in Table 2-7and the JMP service ladder for sanitation for schools is presented in Table 2-8. As mentioned, for a sanitation service to be classified as *improved sanitation*, the facility designed to hygienically separate excreta from human contact. To be a *safely managed sanitation* service (SDG 6.2) all three of the following criteria must be met [WHO and UNICEF, 2017b, 2017c]:

- The sanitation facilities should be improved.

- The sanitation facilities should not be shared with other households or in the case of schools be single sex, accessible to all, of sufficient quantity, and inspected for cleanliness.
- The excreta and wastewater produced should either be:
    - *Treated and disposed of in situ:* Households using toilets or latrines connected to septic tanks or pits, and where the excreta remain stored but considered treated.
    - *Stored temporarily, emptied and treated off-site*: Households using toilets or latrines connected to septic tanks or pits, and where the excreta are emptied and treated off-site, or
    - *Treated off-site*: Households using toilets where the excreta are flushed out of the household, transported through sewers and treated at a treatment plant.

Table 2-7: JMP service ladder for sanitation in households [WHO and UNICEF, 2017b, 2017c]

Service Level	Definition
Safely managed	Use of an improved sanitation facility which is not shared with other households and where excreta are safely disposed in situ or transported and treated off-site
Basic	Use of improved facilities which are not shared with other households
Limited	Use of improved facilities shared between two or more households
Unimproved	Use of pit latrines without a slab or platform, hanging latrines and bucket latrines
Open defecation / No service	No toilets or latrines. Disposal of human faeces in fields, forest, bushes, open bodies of water, beaches or other open spaces or with solid waste

Table 2-8: JMP service ladder for sanitation in schools [UNICEF and WHO, 2016; WHO and UNICEF, 2017b, 2017c]

Service Level	Definition
Safely managed / Advanced	Use of an improved sanitation facility which is single sex, accessible to all, of sufficient quantity, and inspected for cleanliness. Excreta are safely disposed in situ or transported and treated off-site.
Basic	Use of improved facilities which are single sex and usable at the school
Limited	There are improved facilities (flush/pour flush, pit latrine with slab, composting toilet), but not sex-separated or not usable
Unimproved	Use of pit latrines without a slab or platform, hanging latrines and bucket latrines
Open defecation / No service	No toilets or latrines. Disposal of human faeces in fields, forest, bushes, open bodies of water, beaches or other open spaces or with solid waste

The sanitation technologies for improved sanitation include [UNICEF and WHO, 2016; WHO and UNICEF, 2017b]:

- Wet sanitation technologies: Flush and pour flush toilets connecting to piped sewers, septic tanks or pit latrines, ventilated improved pit latrine, composting toilet or pit latrine with slab. With the SDG focus on the safe management of excreta, a distinction is also made between sewered and non-sewered sanitation, as they require different forms of excreta management.
- Dry sanitation technologies: Ventilated improved pit latrines, pit latrines with slabs, or composing toilets.

While septic tanks have certain defining design features (including watertight walls and floor, multiple chambers separated by baffles, and an outlet pipe leading to a soak pit or leach field), many on-site systems lack these features, and should actually be classified as pits (simple vaults or cesspools) [WHO and UNICEF, 2017b]. If the excreta from improved sanitation facilities are not safely managed, then people using those facilities will be classed as having a *basic sanitation service* (SDG 1.4). People using improved facilities that are shared with other households will be classified as having a *limited service*. The JMP will also continue to monitor the population practising open defecation (*no service*), which is an explicit focus of SDG target 6.2.

It should be noted that the JMP indicator for *basic* sanitation services, i.e. ‘population using improved sanitation facilities, which are not shared’, does not take account of excreta management. However, in order to protect communities and children from pathogen exposure, the management of excreta is essential along the entire sanitation chain. International consultations during the development of the 2030 Agenda recommended that downstream management of excreta, in both sewered and non-sewered systems, should be reflected in indicators for national and global monitoring [WHO and UNICEF, 2017b]. To be classified as a *basic sanitation service* in schools, the toilets/latrines should be ‘usable’, which equates to accessible to students (doors are unlocked or a key is available at all times), functional (the toilet should not be broken, the toilet hole is not blocked, and water available for flush/pour-flush toilets), and private (there are closable doors that lock from the inside and no large gaps in the structure). Lockable doors may not be applicable in pre-primary schools.

2.3.4.2 *Normative Criteria for Sanitation Management*

2.3.4.2.1 Accessibility and Safety

“Sanitation facilities must be physically accessible for everyone within, or in the immediate vicinity of, each household, health or educational institution, public institutions and places, and the workplace” [United Nations General Assembly, 2009: p. 24] The distance to the sanitation facility should be in reach of every household and the path leading to the sanitation facility, and the facility itself, should be safe and convenient for all users, bearing in mind the special needs of certain groups and individuals such as children, older people, persons with disabilities (e.g. mobility and visual impairments), women, including pregnant women, and chronically ill people [UNICEF and WHO, 2016; United Nations General Assembly, 2010]. Good practices related to accessibility may include specially designed facilities for people with particular needs, including such features as ramps or handrails for people with disabilities, children or the elderly [United Nations General Assembly, 2009, 2010]. The risk of attack from animals or people, in particular for women and children, and especially girls, has to be considered when choosing where to locate and how to construct the facility to avoid such threats. People must also be able to use sanitation facilities safely at night. This can be facilitated through lighted paths, provision of flashlights, or other measures [United Nations General Assembly, 2010]. Ensuring safe sanitation also requires adequate hygiene promotion and education to encourage individuals to use toilets in a hygienic manner that respects the safety of others [United Nations General Assembly, 2009].

2.3.4.2.2 Availability

To ensure that waiting times are not unreasonably long, human rights law requires that there be a sufficient number of sanitation facilities with associated services within, or in the immediate vicinity, of each household, health or educational institution, public institutions and places, and the workplace [United Nations General Assembly, 2009, 2010]. The minimum number of toilets for a given population will depend on the particularities of a given community and the special needs of each one of its members. For instance, women, persons with disabilities, children and others may have particular sanitation requirements [United Nations General Assembly, 2009, 2010, 2012]. The *safely managed* sanitation services part of the JMP ladder for enhanced global monitoring of sanitation services represent a challenging new global service norm, which is defined as the ‘population using an improved sanitation facility that is not shared with other households, and where excreta are disposed of in situ or transported and treated off-site’. Country estimates for safely managed sanitation are made when information on excreta management is available for at least 50% of the population using the dominant type of improved sanitation facility (sewer connections or on-site sanitation systems) [WHO and UNICEF, 2017b]. In addition to the available facilities, availability may also refer to when individuals (e.g. school children) are permitted to use the sanitation facilities (at all times, during specific times during a school day (such as breaks), etc.) [UNICEF and WHO, 2016]. Globally, the use of basic sanitation services has increased at an average of 0.63 percentage points per year between 2000 and 2015, which is more rapidly than use of basic drinking water services. However, coverage is generally lower for basic sanitation than for basic water, and no SDG region is on track to achieve universal basic sanitation by 2030, except Australia and New Zealand, where coverage is already nearly universal [WHO and UNICEF, 2017b]. In 2015, an estimated 5.3 billion people lacked access to safely managed sanitation services [WHO and UNICEF, 2017b], as illustrated in Figure 2-8. Three out of five people with safely managed sanitation lived in urban areas (1.7 billion and two out of five were in rural areas (1.2 billion). The 4.5 billion people without safely managed sanitation services included 2.1 billion with basic services, 600 million with limited services, 856 million using unimproved sanitation and 892 million still practising open defecation. Although 68% of the global population used at least basic sanitation services in 2015, in Sub-Sharan Africa, only 28% of the population used basic services and 18% had access to limited sanitation services, as illustrated in Figure 2-9 [WHO and UNICEF, 2017b].

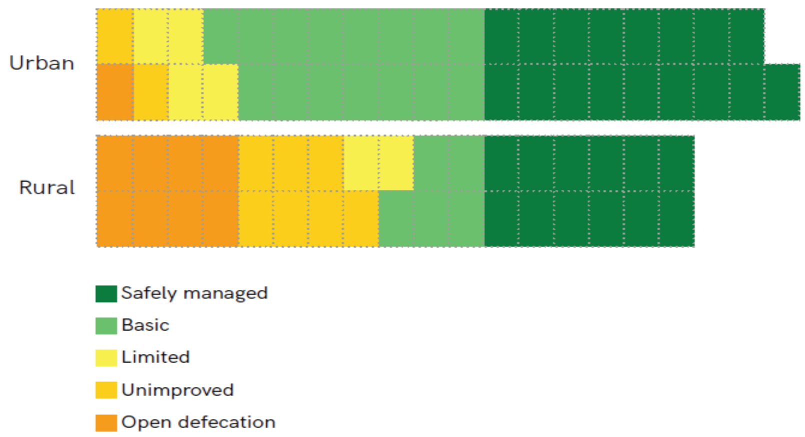


Figure 2-8: Number of people using different levels of sanitation services in 2015 in urban and rural areas (each block represents 100 million people) [WHO and UNICEF, 2017b: p. 29]

Figure 2-9: Proportion of population with at least basic or limited sanitation services, 2015 (%) [WHO and UNICEF, 2017b: p. 14]

2.3.4.2.3 Quality

Human rights require that sanitation facilities must be hygienically safe to use. This means that they must effectively prevent human, animal and insect contact with human excreta Sanitation facilities must have access to safe water and soap for hand washing as well as menstrual hygiene, anal and genital cleansing, as well as mechanisms for the hygienic disposal of menstrual products [United Nations General Assembly, 2009, 2010]. Regular maintenance and cleaning, safely covering of latrines as they fill up, emptying of pits or other places that collect human excreta, cleaning the water point surroundings, and maintenance are essential for ensuring the sustainability of sanitation facilities and continued access [UNICEF and WHO, 2016; United Nations General Assembly, 2009, 2010]. Manual emptying of pit latrines should be avoided and is considered to be unsafe (as well as culturally unacceptable in many places, leading to stigmatization of those burdened with this task) [United Nations General Assembly, 2009, 2010]. Mechanized alternatives that effectively prevent direct contact with human excreta should be used instead [United Nations General Assembly, 2009]. Sanitation facilities must also be technically safe to use, which means that the superstructure is stable and the floor is designed in a way that reduces the risk of accidents (e.g. by slipping). As illustrated in Figure 2-10, improved sanitation facilities (including shared facilities) are globally evenly split between sewer connections and on-site systems, with 2.8 billion people (38%) using sewer connections and another 2.8 billion using septic tanks, latrines or other improved on-site systems [WHO and UNICEF, 2017b], nine out of 10 people using sewer connection lived in urban areas in 2015.

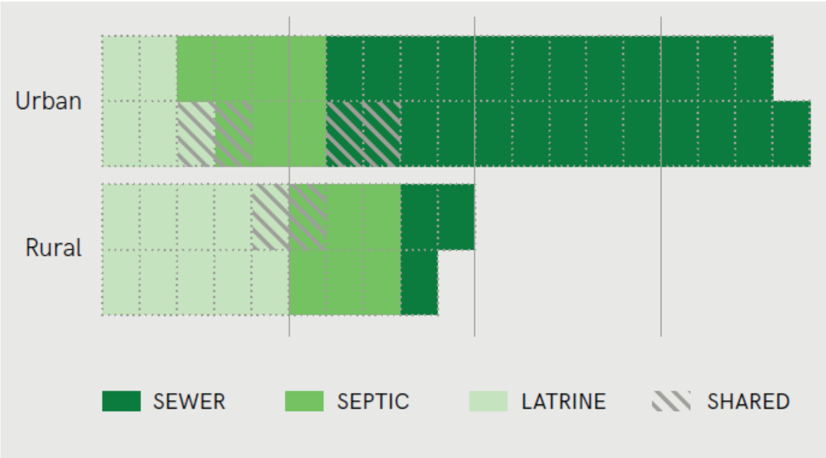


Figure 2-10: Population using different types of improved sanitation facilities, urban and rural, 2015 (each block represents 100 million people) [WHO and UNICEF, 2017b: p. 16]

Although in many countries urban areas are mainly served by sewer connections, on-site sanitation is the principal form of improved sanitation in urban as well as rural areas of Sub-Saharan Africa, Central and Southern Asia, and Oceania, as illustrated in Figure 2-11. An estimated (2 out of 5) people globally, two thirds of those in urban areas (63%) and 1 in 10 in rural areas (9%) report having sewer connections, including shared facilities [WHO and UNICEF, 2017b]. These households are classified as having safely managed sanitation services if the toilets are not shared and if the wastes flushed out of the household *reach a treatment plant* and undergo at least a minimum level of treatment. Having a flushing toilet does not necessarily mean that all excreta flushed down toilets actually reach treatment plants. Toilet lines can, for example, connect to open drains or directly discharge to surface water instead of reaching sewers, or sewage can leak or overflow out of sewers and pumping stations before reaching treatment plants.

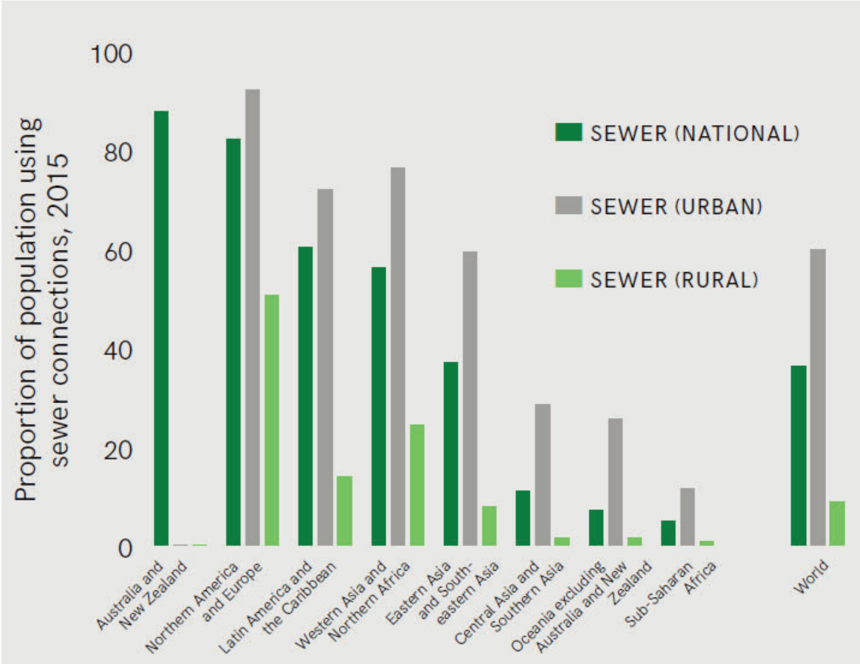


Figure 2-11: Proportion of national population using sewer connections and on-site improved sanitation facilities in 2015, by region (%)

Three levels of sewer-borne wastewater treatment are defined [WHO and UNICEF, 2017b]:

- *Primary treatment where the effluent is discharged through a long ocean outfall*: A mechanical, physical or chemical process, involving settlement of suspended solids or any other process, in which the biochemical oxygen demand (BOD) of the incoming water is reduced by at least 20% before discharge, and the total suspended solids of the incoming water are reduced by at least 50%.
- *Secondary treatment*: A process that follows primary treatment of water and generally involves biological or other treatment with a secondary settlement or other process that results in a biochemical oxygen demand (BOD) removal of at least 70% and a chemical oxygen demand (COD) removal of at least 75%.
- *Tertiary treatment*: A process that follows secondary treatment and removes nitrogen, phosphorous or any other pollutant, such as microbiological pollution or colour, that affects the quality or a specific use of water.

Globally by 2015, 73% of sewer-borne wastewater is estimated to undergo at least secondary treatment. This equates to a population of approximately 1.9 billion people with sewer connections that are classified as having safely managed sanitation services. However, a total of 750 million people, over 90% of who live in urban areas, have sewer connections that do not receive the minimum primary level of treatment [WHO and UNICEF, 2017b].

2.3.4.2.4 Acceptability

Personal sanitation is still a highly sensitive issue across regions and cultures, and perspectives may differ with regard to which sanitation solutions are acceptable in a given context. Services must therefore be culturally acceptable. Good practices related to the acceptability of sanitation facilities and practices should involve a high degree of consultation with users to fully understand their definitions of 'acceptable'. The differing perspectives about which sanitation solutions are acceptable must be taken into account regarding design, location, positioning and conditions for use of sanitation facilities. Facilities should accommodate the differing perspectives about which sanitation solutions are acceptable and take into account common hygiene practices in specific cultures, such as discrete personal hygiene (hand washing, anal and genital cleansing). Women's toilets need to accommodate menstruation needs, including the washing reusable menstrual hygiene products, covered bins for the disposal of hygiene materials, in the design, positioning and conditions for use of sanitation facilities. In many cultures, to be acceptable, toilets must be constructed so as to ensure privacy. Cultural prescriptions may also apply to conditions for use of these facilities. Acceptability also includes the cleaning of the facilities and toilets and refers to both cleanliness and how often the facilities are cleaned. Cleanliness include aspects related to the presence/absence of strong smells, significant numbers of flies or mosquitos, no visible faeces on the floor, walls, seat (or pan) or around the facility [UNICEF and WHO, 2016]. Acceptability will also often require separate facilities for women and men in public places, and for girls and boys in schools [UNICEF and WHO, 2016; United Nations General Assembly, 2009, 2010].

2.3.4.2.5 Affordability

The comments on the affordability of water services, as presented in section 2.3.3.4.4, also apply to sanitation services. Access to sanitation facilities and services, including construction and maintenance of the facilities and the emptying, treatment and disposal of faecal matter, must be available at a price that is affordable for all people without limiting their capacity to acquire other basic goods and services, including water, food, housing, health and education guaranteed by other human rights. Water disconnections resulting from an inability to pay also impact on waterborne sanitation, and this must be taken into consideration before disconnecting the water supply [United Nations General Assembly, 2009]. Table 2-9 presents examples of the different types of costs associated with the provision of sanitation services.

Table 2-9: Examples of different types of costs associated with sanitation services [Hutton, 2012; WHO and UNICEF, 2017b: p. 20]

Service	Recurrent Costs	Capital Costs	Non-Financial Costs
Sanitation	• Wastewater tariff • Public toilet user fees • Maintenance costs	• Toilet construction • Sewer network connection	• Travel time to community facility or open defecation

2.3.5 Criteria and Data for Hygiene

The full benefits of improvements in access to sanitation and drinking water cannot be realized without good hygiene. Although there is a distinction between sanitation and hygiene, the two topics are often covered together in literature. Although the benefits associated with improved of hygiene has long-established links with public health, it was not included in any MDG targets or indicators [WHO and UNICEF, 2017c]. The JMP expert working group on hygiene therefore explored options for global monitoring of hygiene post-2015. From the many hygiene behaviours considered important for health, handwashing with soap was identified as a top priority in all settings. Menstrual hygiene management was also identified as a priority for improving the health, welfare and dignity of women and girls [UNICEF and WHO, 2015]. The WHO and UNESCO in international consultations considered different types of hygiene, including handwashing, menstrual hygiene, and food hygiene, and identified handwashing with soap and water as a top priority in all settings [WHO and UNICEF, 2017c]. SDG 6.2 also addresses hygiene. It states that by 2030 the goal is to "achieve access to adequate and equitable sanitation and *hygiene* for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations” [United Nations General Assembly, 2015: 15] The explicit reference to hygiene in the text of SDG target 6.2 represents increasing recognition of the importance of hygiene and its close links with sanitation [WHO and UNICEF, 2017b]. Hygiene is multi-faceted and can comprise several behaviours, including handwashing, menstrual hygiene and food hygiene. International consultations among WASH sector professionals identified handwashing with soap and water as a top priority in all settings, and also as a suitable indicator for national and global monitoring [WHO and UNICEF, 2017b]. The new global SDG indicator ‘proportion of population with handwashing facilities with soap and water at home’ [United Nations Economic and Social Council, 2016] is defined as the presence of a device to contain, transport or regulate the flow of water to facilitate handwashing with soap and water available [WHO and UNICEF, 2017c].

2.3.5.1 *Handwashing Ladder*

The JMP service ladders for handwashing in households and schools [WHO and UNICEF, 2017c] are presented in Table 2-10 and Table 2-11, respectively. The presence of a handwashing facility with soap and water on premises has been identified as the priority indicator for global monitoring of hygiene. Households that have a handwashing facility with soap and water available on premises will meet the criteria for a *basic hygiene facility*. Households that have a facility, but lack water or soap will be classified as having a *limited facility* and distinguished from households that have *no facility* at all. In some cultures, ash, soil, sand or other materials are used as handwashing agents, but these are less effective than soap and are therefore counted as limited handwashing facilities [WHO and UNICEF, 2017b].

Table 2-10: JMP service ladder for handwashing in households [UNICEF and WHO, 2016; WHO and UNICEF, 2017c]

Service Level	Definition
Advanced*	Handwashing facilities available at critical times and accessible to all
Basic	Hand washing facility with soap *and* water in the household
Limited	Handwashing facility without soap *or* water
No facility	No handwashing facility

* Proposed new level

Table 2-11: JMP service ladder for handwashing in schools [UNICEF and WHO, 2016]

Service Level	Definition
Advanced*	Handwashing facilities available at critical times and accessible to all
Basic	Hand washing facility with soap *and* water in the school
Limited	Handwashing facility with water, but without soap
No facility	No handwashing facility or handwashing facilities with no water

* Proposed new level / To be defined at national level

Handwashing facilities can consist of [WHO and UNICEF, 2017b]:

- A sink with tap water, or
- Other devices that contain, transport or regulate the flow of water, for example buckets with taps, tippy-taps and portable basins. The tippy tap is a hands free way to wash your hands that is especially appropriate for rural areas where there is no running water [tippytap.org].

Handwashing with soap serves as a primary barrier to remove faecal matter from contact with stools and a secondary barrier to prevent pathogens to get into food and fluids consumed by people, allowing pathogens to spread to new hosts [Curtis, Cairncross, & Yonli, 2000]. Soap can include bar soaps, liquid soap, power detergent and soapy water. Soapy water (a prepared solution of detergent suspended in water) can be considered as an alternative for soap, but not for water, as non-soapy water is needed for rinsing [UNICEF and WHO, 2016; WHO and UNICEF, 2017b]. In some cultures, ash, soil, sand or other materials are used as handwashing agents, but these are less effective than soap and are therefore counted as limited handwashing facilities [WHO and UNICEF, 2017b]. Handwashing facilities are not limited to those in available in/at sanitation facilities. It also refers to facilities available at food preparation areas, food consumption areas, classrooms, etc. The Centers for Disease Control and Prevention (CDC) recommend washing of hands [Centers for Disease Control and Prevention, 2016; McKeever, 2014]:

- Before, during, and after preparing food.
- Before eating food.
- Before and after caring for someone who is sick.
- Before and after treating a cut or wound.
- After using the toilet.
- After changing diapers or cleaning up a child who has used the toilet.
- After blowing your nose, coughing, or sneezing.
- After touching an animal, animal feed or animal waste.
- After handling pet food or pet treats.
- After touching garbage.

2.3.5.2 *Normative Criteria for Hygiene in general*

2.3.5.2.1 Accessibility and Safety

This is related to the accessibility of sanitation facilities (section 2.3.4.2.1) and the accessibility of water (section 2.3.3.4.1). Good hand-washing practices must be supported with consistent access to water and adequate supplies of soap [UNICEF, 2012].

2.3.5.2.2 Availability and Quality

The availability of hygiene services is often related to the availability of sanitation facilities (section 2.3.4.2.2), the availability and quality of water (section 2.3.3.4.2 and 2.3.3.4.3) and menstrual hygiene management. Handwashing facilities are, however, not limited to those available in/at sanitation facilities. It also refers to facilities available at food preparation areas, food consumption areas, classrooms, etc. [UNICEF and WHO, 2016]. Figure 2-12 indicates the available 2015 JMP data for hygiene, based on the national population with basic handwashing facilities including soap and water at home [WHO and UNICEF, 2017b].

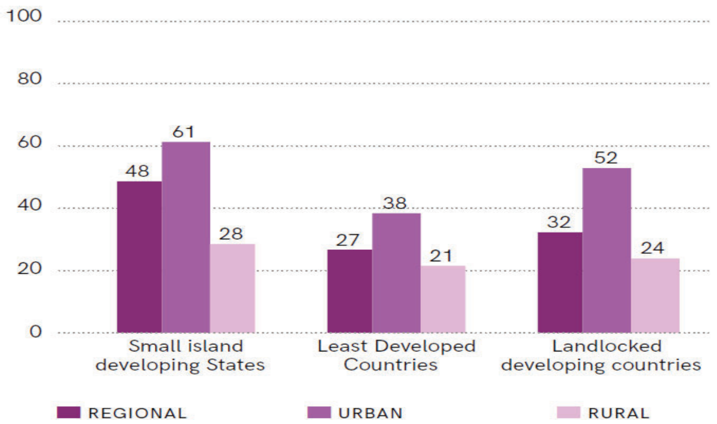


Figure 2-12: National population with basic handwashing facilities including soap and water at home, by region, 2015 (%) [WHO and UNICEF, 2017b: p. 26]

Coverage was higher in urban areas for all the regions surveyed. A systematic review of global handwashing practices in 2012 showed that handwashing after possible contact with excreta is still far from universally practiced. The global mean prevalence of handwashing was estimated to be only 19% [Freeman, Stocks, et al., 2014].

2.3.5.2.3 Affordability

See Table 2-12, providing examples of the different types of costs associated with the provision of hygiene services. The 2012 study on global handwashing practices showed little variance within regions of the same income level. The high-income countries with data on handwashing frequency show rates varying between 48% and 72%, and low-income countries show lower rates varying between 5% and 25% [Freeman, Stocks, et al., 2014].

2.3.5.3 *Menstrual Hygiene Management*

Access to basic facilities for menstrual hygiene management (MHM) is critically important for women's health, safety and dignity. Although no JMP ladder currently exist for MHM, several essential elements have been identified as required for MHM. This include clean materials to absorb or collect menstrual blood, a private place to change these materials as often as necessary, soap and water for washing the body as required, and access to safe and convenient facilities to dispose of used materials [UNICEF and WHO, 2015]. Further, women and girls need access to basic information about the menstrual cycle and how to manage it with dignity and without discomfort or fear. UNICEF and WHO [2016] calls for an inclusion of the requirement 'menstrual hygiene education and products provided' under the advanced service level to be included in the hygiene ladder for schools (see Table 2-11).

2.3.5.4 *Normative Criteria for MHM*

Globally, there is very little comparable information available on MHM. There is, however, a growing interest in monitoring WASH in institutional settings such as schools and health care facilities, which provides a useful entry point for monitoring MHM. The availability of adequate facilities in public places is generally easier to measure than within the privacy of the household. Questions to ascertain knowledge, behaviour and access to facilities and materials are also being tested and validated for potential inclusion in household surveys and may offer a complementary means of monitoring MHM.

2.3.5.4.1 Accessibility and Safety

This is related to the accessibility of sanitation facilities (section 2.3.4.2.1) and the accessibility of water (section 2.3.3.4.1).

2.3.5.4.2 Availability

This is related to the availability of sanitation facilities (section 2.3.4.2.2), the availability and quality of water (section 2.3.3.4.2 and 2.3.3.4.3). MHM is linked to good hand-washing practices, which must be supported with consistent access to water and adequate supplies of soap. Globally, there is very little comparable information available on MHM. There is, however, a growing interest in monitoring WASH in institutional settings such as schools and health care facilities, which may provide a useful entry point for monitoring MHM. The availability of adequate facilities in public places is generally easier to measure than within the privacy of the household. As a complementary means of monitoring MHM, questions to ascertain knowledge, behaviour and access to facilities and materials are also being tested and validated by JMP for potential inclusion in household and school surveys [UNICEF and WHO, 2015, 2016]. However, the lack of basic sanitation and drinking water facilities (see section 2.3.4.2.2), suggests that many women lack a suitable place for managing menstruation. Assuming that in 2015 at least half of the 856 million people globally who lack any kind of facility and defecate in the open are female, a conservative estimate would suggest that at least 450 million women and girls lack adequate facilities for MHM [UNICEF and WHO, 2015; WHO and UNICEF, 2017b].

2.3.5.4.3 Quality and Acceptability

Facilities should accommodate the common hygiene practices in specific cultures, such as discrete personal hygiene (hand washing, anal and genital cleansing) and the availability of culturally appropriate anal cleansing material. Women's toilets need to accommodate menstruation needs, including, for example, bathing areas, the washing of reusable menstrual hygiene products, covered bins for the disposal of hygiene materials, in the design, positioning and conditions for use of sanitation facilities. Other disposal mechanisms can include incineration or another safe method on-site, or safe storage and collection via a municipal waste system, as appropriate [UNICEF and WHO, 2016; United Nations General Assembly, 2009, 2010]. With regards to WASH in schools, UNICEF and WHO [2016] specify that bathing areas could be separate from latrines and toilets or included in the same enclosure. The design may vary based on local context, but at minimum should be private (have closable doors lockable from the inside, and no holes, cracks, windows or low walls that would permit others to see in) and have water and soap available inside the enclosure. They also include the availability of MHM material (via free distribution or for purchase) and the institutionalisation of MHM education (i.e. regularly taught in class or through a regular school program) for schools.

2.3.5.4.4 Affordability

Table 2-12 presents examples of the different types of costs associated with the provision of hygiene services.

Table 2-12: Examples of different types of costs associated with hygiene services [WHO and UNICEF, 2017b: p. 20]

Service	Recurrent Costs	Capital Costs	Non-Financial Costs
Hygiene	• Purchase of soap • Menstrual hygiene materials • Maintenance costs	• Handwashing station • Bins for menstrual materials	• Collection of water for handwashing and anal cleansing

2.3.6 **Diseases related to WASH**

The availability and use of WASH services and practices are important risk factors, particularly in low-income contexts:

- In 2015, an estimated 663 million people relied on 'unimproved' water supplies [UNICEF and WHO, 2015] which are thought to have high levels of pathogen contamination [Prüss-Ustün et al., 2014]. By 2017 at least 844 million people lacked a basic water service and at least 159 million people still collected drinking water directly from surface water resources, of which 58% lived in Sub-Saharan Africa [WHO and UNICEF, 2017b]. Many more people make use of water sources that are classified as 'improved', but which are still unsafe for human consumption [Bain et al., 2014].

Any breakdown in water supply safety (source, treatment and distribution) may lead to large-scale contamination and potentially to disease outbreaks. The most common and widespread health risk associated with drinking-water is that of infectious diseases caused by pathogenic bacteria, viruses, protozoa and helminths [WHO, 2011]. The public health burden is determined by the severity and incidence of the illnesses associated with pathogens, their infectivity and the population exposed. In vulnerable subpopulations, disease outcome may be more severe.

- In 2015, an estimated 5.3 billion people lacked access to safely managed sanitation services. Of these, 2.3 billion still lacked access to a basic sanitation service [WHO and UNICEF, 2017b].
- Inadequate hand hygiene practices are estimated to affect 80% of the population globally. Handwashing with soap has been shown to have important health benefits across the globe, especially in low- and middle-income countries. Handwashing with soap is among the most effective and inexpensive ways to prevent certain diseases, including the prevention of diarrhoea [Freeman, Clasen, et al., 2014; Freeman, Stocks, et al., 2014] and acute respiratory infections, such as influenza [Ram, 2013]. Every year, 1.4 million children do not live to the age of 5, because of diarrhoea and pneumonia. Handwashing can save lives, cutting diarrhoea by almost one-half and acute respiratory infections by nearly 25%.

The global burden of disease (GBD) for WASH related causes are very high. Exposure to pathogens may lead to disease or infection. The number of microorganisms (dose) that may cause diseases or infections will depend on the specific pathogen encountered, the form in which it is encountered, the conditions of exposure and the host's susceptibility and immune status. For viral and parasitic protozoan illness, this dose might be very few viable infectious units. The types and numbers of pathogens in sewage in a particular region will differ depending on the incidence of disease and carrier states in the contributing human and animal populations, as well as the seasonality of infections. Numbers will therefore vary greatly across different parts of the world and times of year. A general indication of pathogen numbers in raw sewage is given in Table 2-13 [WHO, 2003]. The following are diseases that could prevented if adequate water quality and quantity, sanitation facilities, hygiene behaviour, as well as water resource management interventions were implemented [GBD 2015 Risk Factora Collaborators, 2016; Prüss-Ustün et al., 2014; WHO, 2017b]:

- Diarrhoeal diseases
- Typhoid fever
- Paratyphoid fever
- Acute respiratory infections, including influenza, lower respiratory infections (pneumonia)
- Malnutrition
- Intestinal nematode infections
- Lymphatic filariasis
- Trachoma
- Schistosomiasis
- Malaria
- Japanese encephalitis
- Dengue
- Onchocerciasis
- Hepatitis A, E, F
- Legionellosis
- Scabies
- Arsenicosis
- Fluorosis
- Methaemoglobinaemia
- Onchocerciasis
- Ascariasis

- Hookworm
- Trichuriasis and others

Table 2-13: Examples of pathogens and index organism concentrations in raw sewage [WHO, 2003: p. 52]

Pathogen Group	Organism Name	Disease/Role	Numbers per 100ml
Bacteria	*Campylobacter* spp.	Gastroenteritis	10^4-10^5
	Clostridium perfringens spores	Index organism	6 x 10^4-8 x 10^4
	Escherichia coli	Index organism (except specific strains)	10^6-10^7
	Faecal streptococci/intestinal enterococci	Index organism	4.7 x 10^3-4 x 10^5
	Salmonella spp.	Gastroenteritis	0.2-8000
	Shigella spp.	Bacillary dysentery	0.1-1000
Viruses	Polioviruses	Index organism (vaccine strains), poliomyelitis	180-500 000
	Rotaviruses	Diarrhoea, vomiting	400-85 000
	Adenoviruses	Respiratory disease, gastroenteritis	Not enumerated yet*
	Norwalk viruses	Diarrhoea, vomiting	Not enumerated yet*
	Hepatitis A	Hepatitis	Not enumerated yet*
Parasitic protozoa **	*Cryptosporidium parvum* oocysts	Diarrhoea	0.1-39
	Entamoeba histolytica	Amoebic dysentery	0.4
	Giardia lamblia cysts	Diarrhoea	12.5-20 000
Helminths (ova) **	*Ascaris* spp.	Ascariasis	0.5-11
	Ancylostoma spp. and *Necator* sp.	Anaemia	0.6-19
	Trichuris spp.	Diarrhoea	1-4

* Many important pathogens in sewage have yet to be adequately enumerated, such as adenoviruses, Norwalk-like viruses and the Hepatitis A virus.
** Parasite numbers vary greatly due to differing levels of endemic disease in different regions.

Table 2-14 provides the results of a systematic analysis and synthesis by the GBD 2015 Risk Factors Collaborators of the evidence for risk factor exposure in the WASH domain, the attributable to examples of diseases and the resulting estimated number of all-age deaths and DALYs [1] globally in 2015 [GBD 2015 Risk Factora Collaborators, 2016].

[1] DALYs: Disability-adjusted life-years is a measure of overall disease burden, expressed as the number of years lost due to ill-health, disability or early death. DALYs for a specific disease or health condition are calculated as the sum of the 'years of life lost' (YLL) due to premature mortality in the population and the 'years lost due to disability' (YLD) for people living with the health condition or its consequences [WHO, 2017a].

Table 2-14: 2015 global all-age deaths and DALYs attributable to WASH risk factors [GBD 2015 Risk Factora Collaborators, 2016]

WASH Element	Source	Disease	Attributable Deaths (in thousands)	DALYs (in thousands
Water	Unsafe/ unimproved /improved water source with improper point-of-use treatment (chlorinating or solar filtering, boiling, filtering, etc.) or storage	Diarrhoeal diseases	± 1101	± 61 104
	Unsafe/ unimproved /improved water source with improper point-of-use treatment (chlorinating or solar filtering, boiling, filtering, etc.) or storage	Typhoid fever	± 126	± 8943
	Unsafe/ unimproved /improved water source with improper point-of-use treatment (chlorinating or solar filtering, boiling, filtering, etc.) or storage	Paratyphoid fever	± 25	± 1699
Sanitation	Unimproved or improved sanitation except for sewer connection	Diarrhoeal diseases	± 720	± 40 005
	Unimproved or improved sanitation except for sewer connection	Typhoid fever	± 74	± 5290
	Unimproved or improved sanitation except for sewer connection	Paratyphoid fever	± 14	± 981
Hygiene	No handwashing with soap and water	Diarrhoeal diseases	± 502	± 27 628
	No handwashing with soap and water	Typhoid fever	± 56	± 4019
	No handwashing with soap and water	Paratyphoid fever	± 11	± 763
	No handwashing with soap and water	Lower respiratory infections	Not available	Not available

2.3.7 Human Behavioural Factors Related to WASH Services

Enabling products and technologies are some of the 'intentional external factors' that influence individuals' likelihood to perform a behaviour, regardless of their ability and motivation to take action [Devine, 2009]. Behaviour change is most successful if the behaviour is not only intentional, but also feasible for the target population to adopt. Traditional approaches to improving WASH services have often not achieved significant and sustained usage coverage since it often focuses only on building facilities. To achieve continued success a combination of technical approaches and behavioural determinants, such as attitudes and beliefs about sanitation and handwashing, knowledge about the positive consequences of handwashing, consuming save water, etc. is required. Strategies concentrating on creating demand for improved sanitation and hygiene, by changing behaviours at the same time as strengthening the availability of supporting products and services have yielded more promising results [Devine, 2009]. It is therefore important to understand WASH behaviours before any changes or improvements are implemented. For example, what factors enable or inhibit individuals or households to move up the sanitation ladder where they progress from open defecation, to the use of simple latrines, to the use of more improved options such as toilets connected to a sewer [Devine, 2009]? What factors inhibit them from doing so? A number of theoretical models, explanatory frameworks, and decision-making models have emerged over time with the aim to guide behaviour change interventions related to WASH. Table 2-15 provides an overview of some of the models and frameworks that are applicable to low and middle-income countries or infrastructure constrained settings.

Table 2-15: Behaviour change models and frameworks in WASH (adapted from [Dreibelbis et al., 2013])

Study	Behaviour or outcome of focus	Included determinants
The Hygiene Improvement Framework [Environmental Health Project (EHP), UNICEF Water, US Agency for International Development (USAID), World Bank Water and Sanitation Program (WSP), & Water Supply and Sanitation Collaborative Council (WSSCC), 2004]	Diarrheal prevention	• Access to hardware: water supply systems, improved sanitation, household technologies • Hygiene promotion: communication, social mobilization, community participation, social marketing, advocacy • Enabling environment: policy improvement, institutional strengthening, community organisation, financing, partnerships
Acceptability of solar disinfection (SODIS) of drinking water treatment [Rainey & Harding, 2005]	Household water treatment	• Application of the Health Belief Model, including: • Individual perceptions: perceived severity and perceived susceptibility to disease • (diarrhoea) • Modifying factors: demographic variables, socio-economic variables, structural variables; perceived threat of disease; cues to action • Likelihood of Action: perceived benefits of taking action minus perceived barriers, perceived efficacy of action and ability to complete it, likelihood of taking action
Behavioural indicators of household decision-making and demand [Jenkins & Scott, 2007]	Sanitation	• Preference (motivation): dissatisfaction with current practices, awareness of options • Intention: priority of change among competing goals, absence of permanent constraints to acquiring sanitation • Choice: absence of temporary constraints to acquiring sanitation
Hygiene behaviour [Curtis, Danquah, & Aunger, 2009; Curtis et al., 2011]	Handwashing with soap	• Planning: teaching children manners Motivation: disgust, norms, conform, nurture • Habit: train children, tips to train oneself • Social norms

Study	Behaviour or outcome of focus	Included determinants
FOAM and SaniFOAM [Coombes & Devine, 2010; Devine, 2009, 2010]	Handwashing (FOAM) and Sanitation (SaniFOAM)	• Physical facilities: cues, costs • Biological signs of contamination • Opportunity: access / availability, product attributes, social norms (FOAM), sanction / enforcement (SaniFOAM) • Ability: knowledge, social support (FOAM), skills and self-efficacy, roles and decisions, affordability (SaniFOAM) • Motivations: beliefs and attitudes, outcome expectations, threat, intention (FOAM), values, emotional/physical/social drivers competing priorities, willingness-to-pay (SaniFOAM)
Social, cultural, and behavioural correlates [Figueroa & Kincaid, 2010]	Household water treatment and storage	• Individual: knowledge / skills, attitudes, perceived risk and severity, subjective norms, self-image, emotional response, self-efficacy, empathy & trust, social influence, personal advocacy • Household: time allocation, family support, resources, decision making Community: value for water quality, leadership, action, resources, cohesion Environmental/context: burden of disease, WASH technologies, community • infrastructure, socio-demographic infrastructure, income inequality
Use and need of Waterguard hygiene kits [Wood, Foster, & Kols, 2012]	Household water treatment (filters)	• Awareness: Perceived need, awareness of products, assess value of products and relevance to lives • Action: trial / initial use, sustained use • Maintenance: purchase, sustained use
Psychological model for behaviour [Mosler, 2012]	WASH practices (general)	• Risk factors: perceived vulnerability, perceived severity, factual knowledge • Attitude factors: Instrumental beliefs, affective beliefs • Normative factors: descriptive, injunctive, and personal norm • Ability factors: Action knowledge, self-efficacy, maintenance efficacy, recovery efficacy • Self-regulation factors: action control / planning, coping planning, remembering, commitment

A review of these models [Dreibelbis et al., 2013] found that most of the existing models under-represented the potential role of technology in influencing behavioural outcomes, focused on individual-level behavioural determinants, or largely ignored the role of the physical and natural environment. In an attempt to correct this, the IBM-WASH model was developed [Dreibelbis et al., 2013]. IBM-WASH is an integrated behavioural model for water, sanitation and hygiene that outlines key factors that influence behaviour in WASH. It consists of three factor dimensions (contextual, psychosocial technology) that operate on five levels (structural, community, household, individual, and habitual), as presented in Table 2-16. The IBM-WASH model can be used as a conceptual and practical tool for improving our understanding and evaluation of the multi-level multi-dimensional factors that influence WASH practices in infrastructure-constrained settings. Examples provided in Dreibelbis et al. [2013] include the psychosocial and technology dimensions applied to community-based chlorine dispensers, and the full framework applied to the use of child potties.

Table 2-16: The Integrated Behavioural Model for Water, Sanitation, and Hygiene (IBM-WASH) [Dreibelbis et al., 2013: p. 6]

Levels	Contextual factors	Psychosocial factors	Technology factors
Societal / Structural	Policy and regulations, climate and geography	Leadership/advocacy, cultural identity	Manufacturing, financing, and distribution of the product; current and past national policies and promotion of products
Community	Access to markets, access to resources, built and physical environment	Shared values, collective efficacy, social integration, stigma	Location, access, availability, individual vs. collective ownership/access, and maintenance of the product
Interpersonal / Household	Roles and responsibilities, household structure, division of labour, available space	Injunctive norms, descriptive norms, aspirations, shame, nurture	Sharing of access to product, modelling / demonstration of use of product
Individual	Wealth, age, education, gender, livelihoods/employment	Self-efficacy, knowledge, disgust, perceived threat	Perceived cost, value, convenience, and other strengths and weaknesses of the product
Habitual	Favourable environment for habit formation, opportunity for and barriers to repetition of behaviour	Existing water and sanitation habits, outcome expectations	Ease/effectiveness of routine use of product

2.4 CONTEXT OF WASH SERVICES DELIVERY IN SOUTH AFRICA

2.4.1 Regulatory Context

This section addresses the South African context by specifically looking at the WASH sector as it relates to the associated concepts of safe drinking water, safe sanitation, and hygiene with a specific reference to handwashing. There is no integrated WASH sector in South Africa. Responsibility for WASH services on government level spread over various national and provincial departments, with overlapping mandates. Some of the prominent national government departments in the WASH sectors are the:

- Department of Water and Sanitation
- Department of Cooperative Governance and Traditional Affairs
- Department of Human Settlements
- Department of Health

- Department of Basic Education
- Department of Social Development
- Department of Environmental Affairs
- Department of Public Works.

Apart from the Constitution of the Republic of South Africa [Constitutional Assembly, 2013], which states that everyone has the right to have access to sufficient water, the Water Services Act (No 108 of 1997) [Republic of South Africa, 1997b] and the National Water Act (No 36 of 1998) [Republic of South Africa, 1997a] provide the primary basis for the legislative framework within which water supply and sanitation services, water resource management and water use need to take place. In addition to these Acts, there are a number of associated pieces of legislation that contribute toward the defining of the legislative framework for the WASH sector in South Africa. This section introduces some of these legislative documents relevant to the WASH sector. Several national policies and plans address aspects of WASH. For example, the National Development Plan 2030 (NDP) [National Planning Commission, 2013] offers a long-term perspective. It defines a desired destination and identifies the role different sectors of society need to play in reaching that goal. In contrast, the Medium-Term Strategic Framework (MTSF) [Department of Planning, 2014] addresses some medium-term aspects related to water and sanitation, primarily to improve access and improving infrastructure. The following sections provide an overview of these and other relevant legislation, policies and plans as they apply to the various WASH domains.

2.4.2 **Strategic Planning Frameworks for WASH Services in SA**

2.4.2.1 *Water*

The NDP [National Planning Commission, 2013] makes a commitment to achieving a minimum standard of living for all people in South Africa and acknowledges water as a strategic resource in achieving this goal. Concerning water, the NDP aims to ensure that all South Africans have access to sufficient, safe and clean running water in their homes by 2030. It proposes a comprehensive management strategy for water resources, including investment programmes for water resource development, bulk water supply and wastewater management. The NDP also highlights the fact that South Africa is a dry country with limited fresh water resources, which will require sensible use or existing water resources. The NDP asserts that water supply and sanitation services, which depend on adequate management, are a priority for most South African communities. Their effective and sustainable management is essential for community health, development and cohesion, and continued economic activity. Service provision arrangements are expected to vary in different parts of the country, with different approaches adopted for densely built-up urban areas and scattered rural settlements. Apart from the continued responsibility of local governments for ensuring service provision in their areas and, alternative solutions such as community-based management, local franchising or the use of regional water utilities will be allowed, if they prove to be more effective [National Planning Commission, 2013].

The MSTF identifies two key targets for water, namely to [Department of Planning, 2014]:

- Increase bulk water resources commissioned with 5% by 2019 in comparison to the status in 2014.
- Increase the percentage of households with access to a functional water service from 85% in 2013 to 90% by 2019.

Measures to ensure water security and healthy catchments, rivers and wetlands will be enforced. The focus is on the maintenance and supply availability of bulk water resources infrastructure, including dams and inter-basin transfers, bulk water reticulation and wastewater systems. Full access to affordable and reliable water is envisaged before 2030 [Department of Planning, 2014].

2.4.2.2 *Sanitation*

Sanitation services are reliant on water resources to address basic hygiene needs such as hand washing, food preparation and to cleaning of households and sanitation systems. Water resources also play a vital role in the sustainable operation of many of the sanitation systems that are utilised in the country [Department of Water and Sanitation, 2016]. The NDP 2030 envisages that all South Africans will have affordable, reliable access to hygienic sanitation by 2030 [National Planning Commission, 2013]. The MSTF identifies a key target for sanitation, namely to increase in the percentage of households with access to a functional sanitation service from 84% in 2013 to 90% by 2019, including elimination of bucket sanitation in the formal areas. It also aims to reduce differences in access to quality healthcare, education and training, clean water and adequate sanitation. Full access to affordable and reliable water and sanitation is envisaged before 2030 [Department of Planning, 2014]. The mandate for the South African Department of Water and Sanitation includes the regulation of the sanitation sector in the country, as well as provision of macro planning, regional bulk services and monitoring. The National Sanitation Policy 2016 for South Africa [Department of Water and Sanitation, 2016] considers sanitation policy positions across the entire sanitation value chain, namely the collection, removal, disposal or treatment of human excreta and domestic wastewater, and the collection, treatment and disposal of industrial wastewater. The Policy also endorses the national sanitation targets, as outlined in the National Development Plan (NDP) and Medium Term Strategic Framework (MTSF).

Sanitation services are defined as the "collection, removal, treatment and/or disposal of human excreta," domestic and "public institution wastewater, and the collection, treatment and/or disposal of municipal, agricultural, mining and industrial wastewater. This includes all the organisational arrangements necessary to ensure the provision of sanitation services including, among others, consideration of natural resources, social acceptance, appropriate health, hygiene and sanitation-related awareness and technologies, the measurement of the quantity and quality of discharges where appropriate, apply the polluter pays principle, the associated billing, collection of revenue and consumer care" [Department of Water and Sanitation, 2016: p. 10] .

Basic sanitation services are defined as "the provision of a basic sanitation facility which is environmentally sustainable, easily accessible to a household and a consumer, the sustainable operation and maintenance of the facility, including the safe removal of human waste, greywater and wastewater from the premises where this is appropriate and necessary, and the communication and local monitoring of good sanitation, hygiene and related practices " [Department of Water and Sanitation, 2016: p. 9].

The minimum acceptable *basic level* of sanitation is [Department of Water and Sanitation, 2016: p. 8]:

- "appropriate health and hygiene awareness and behaviour;
- the lowest cost, appropriate system for disposing of human excreta, household wastewater, greywater, which considers resource constraints, is acceptable and affordable to the users, safe including for children, hygienic and easily accessible and which does not have a detrimental impact on the environment;
- a toilet and hand washing facility;
- to ensure clean living environment at a household and community level; and
- the consideration of defecation practices of small children and people with disabilities and special needs".

The Policy also defines the minimum acceptable level of sanitation facilities by stating that the infrastructure should consider [Department of Water and Sanitation, 2016: p. 9]:

- "natural (water; land; topography) resource protection,
- is safe (including for children),

- reliable,
- private,
- socially acceptable,
- skilled and capacity available locally for operation and maintenance,
- protected from the weather and ventilated,
- keeps smells to the minimum,
- is easy to keep clean,
- minimises the risk of the spread of sanitation-related diseases by facilitating the appropriate control of disease carrying flies and pests,
- facilitates hand washing and
- enables safe and appropriate treatment and/or removal of human waste and wastewater in an environmentally sound manner".

2.4.2.3 *Hygiene*

Hygiene is not explicitly addressed in either the NDP or the MSTF. The National Sanitation Policy 2016 [Department of Water and Sanitation, 2016] includes the communication of good hygiene and related practices in its definition of basic sanitation services. The Policy takes the position that all public and private institutions are responsible to provide sanitation services, including hand washing facilities, hygiene and end-user education. Integrated planning of hygiene education programmes alongside water supply and sanitation projects are indicated as a prerequisite of all water supply and sanitation projects and should be ongoing post construction. Hygiene messages should target urban, rural and peri-urban areas and include [Department of Water and Sanitation, 2016]:

- *Personal hygiene*: Including washing hands after going to the toilet, changing the nappies of babies, before the preparation of food, and before you eat or feed a child. There should also be a special focus on vulnerable individuals and groups affected by chronic diseases.
- *Household hygiene*: Including keeping the home clean, particularly those areas where food is stored and prepared, and ensuring that food and drinking water is kept covered and uncontaminated.
- *Environmental hygiene*: Including safe solid waste storage and disposal.
- *Community hygiene*: Hygiene is not limited to household boundaries. Improved public health requires that the entire community be mobilised to work together for better health and a cleaner environment.
- *Community participation*: It is important to involve the community and local leadership structures in all aspects of programmes to ensure their relevance and acceptability.

The National Health Promotion Policy and Strategy 2015-2019 [Department of Health, 2015] promotes the establishment of conducive environments for the promotion of healthy behaviours through coordinated inter-sectoral action for the promotion of handwashing, personal hygiene practices, healthy eating options and personal safety. In a follow-up, the National Department of Health launched a National Hand Hygiene Behaviour Strategy in 2016 [Department of Health, 2016a]. Implementation of the Strategy commenced in 2017 [UNICEF, 2017]. The Strategy focuses on three core components of hygiene promotion, namely advocacy, education and awareness, and behaviour change. The concept document for the commemoration of Global Handwashing Day in 2016 [Department of Health, Department of Water and Sanitation, Department of Social development, & Department of Basic Education, 2016] included a fact sheet on handwashing to assist in promotions. The National Health Act 61 of 2003 [Republic of South Africa, 2004] delegates the responsibility for municipal health services to district and metropolitan municipalities. This is in line with the Municipal Structures Act 117 of 1998 and its various amendments until 2006 [Republic of South Africa, 1998], which indicates that municipal health services, and thus health and hygiene education, awareness and promotion, are a function of metro and district municipalities. A 2012 WRC study [Wilkinson et al., 2013], provides an overview of the hand hygiene landscape in South

Africa, and provides a framework that can be used for hand hygiene assessment in South Africa. The framework includes determinants (handwashing water quality and hand hygiene techniques or procedures) and indicators of hand hygiene behaviours (cultural influences, media exposure, hand hygiene service environment, and the influence of hand hygiene knowledge).

2.4.3 **WASH Services Delivery Monitoring and Data for South Africa**

According to UNICEF [2017] the leading underlying cause of death in South Africa among children between the age of 1 and 14 years is intestinal infectious diseases. Almost 30% of deaths among children aged 1 to 4 years are attributable to diarrhoea, pneumonia/influenza and malnutrition. An estimated 2.6 million households do not have access to safe drinking water and approximately 400 000 households do not have a toilet facility. An estimated 29% of schools have an unimproved pit latrine or no toilet facility at all. UNICEF works closely with the Departments of Health, Basic Education and Water and Sanitation, as well as other private sector and non-governmental partners to deliver multi-sectoral action on WASH at all levels. UNICEF [2017] reports on the following successes achieved through his collaboration:

- WASH targets have been integrated in the health facility scorecard used in Ideal Clinics.
- Introduction of a Government-sponsored deworming programme ensures that 7 million tablets are distributed each year to disadvantaged schools.
- An estimated 800 000 adolescents and young people have been engaged through TV and social media programmes to promote good WASH practices.
- Nearly 50 000 learners have been reached with participatory health and hygiene promotion programmes through puppet shows in 131 schools across five provinces.
- More than 8 500 community health workers have been trained to promote WASH in their communities. Eighty per cent of people visited by healthcare workers in KwaZulu-Natal said they have changed their handwashing and hygiene behaviour as result.
- Simple and safe water solutions such as tippy taps [tippytap.org] have been introduced in four disadvantaged communities within eThekwini and Buffalo City metros, providing lessons for scale-up across the country. The taps not only provide running water, but also serve as a visual reminder and encouragement to engage in handwashing with soap.

The General Household Survey (GHS) of 2016 [StatsSA, 2017] was conducted by Statistics South Africa (StatsSA) from January to December 2016. The GHS covers six broad areas, namely education, health and social development, housing, household access to services and facilities, food security, and agriculture. The following sections provided a summary of the GHS survey results and other data that apply to the WASH sector.

2.4.3.1 *Water*

2.4.3.1.1 Availability and Accessibility of Water

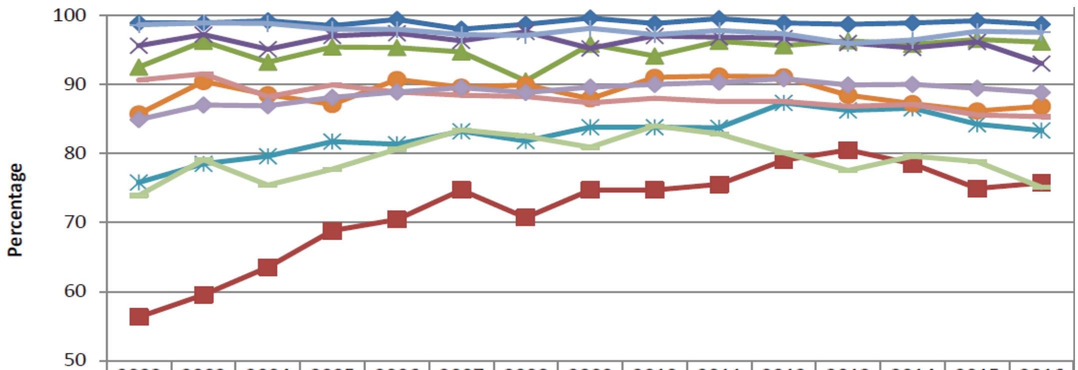
Table 2-17 presents a comparison of the main sources of drinking water used by households as reflected in the 2016 GHS [StatsSA, 2017]. Using the JMP water ladder (see section 2.3.3.1), the percentages are [StatsSA, 2017]:

- *Safely managed water (piped water on premises)*: Approximately 46.4% of households had access to piped water in their dwellings in 2016 and 26.8% accessed piped water on site.
- Bas*ic improved water (piped water not on premises)*: A further 13.3% of households relied on water from communal taps and 2.4% relied on water from neighbours' taps (called RDP standard in the GHS, provided that the distance to the water source is less than 200 metres).
- *Unimproved water resources*: An estimated 3.7% of households in 2016 still had to fetch water from rivers, streams, stagnant water pools, dams, wells and springs (down from 9.5% in 2002).

Table 2-17: Main water source for drinking used by households in South Africa, 2002-2016 [StatsSA, 2017: p. 37]

Water source		Year												
		2002	2004	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Piped water in dwelling	N	4 409	4 607	4 980	5 163	5 611	5 622	5 862	6 294	6 504	6 845	7 221	7 385	7 728
	%	40,8	40,4	41,2	41,6	43,7	42,3	42,7	44,4	44,5	45,3	46,3	45,8	46,4
Piped water on site	N	3 009	3 367	3 681	3 838	3 501	3 743	4 019	4 106	4 055	4 051	4 213	4 354	4 458
	%	27,8	29,5	30,5	30,9	27,3	28,1	29,3	29	27,7	26,8	27,0	27,0	26,8
Borehole on site	N	290	188	141	155	155	190	157	212	203	259	293	259	305
	%	2,7	1,6	1,2	1,3	1,2	1,4	1,1	1,5	1,4	1,7	1,9	1,6	1,8
Rainwater tank on site	N	142	38	49	61	68	44	45	91	82	74	68	120	132
	%	1,3	0,3	0,4	0,5	0,5	0,3	0,3	0,6	0,6	0,5	0,4	0,7	0,8
Neighbour's tap	N	60	260	250	265	336	358	346	388	424	388	426	431	400
	%	0,6	2,3	2,1	2,1	2,6	2,7	2,5	2,7	2,9	2,6	2,7	2,7	2,4
Public/ communal tap	N	1 465	1 682	1 852	1 910	1 996	2 201	2 131	2 008	2 307	2 290	2 180	2 247	2 209
	%	13,6	14,7	15,3	15,4	15,6	16,5	15,5	14,2	15,8	15,2	14,0	13,9	13,3
Water-carrier/ tanker	N	68	69	134	123	146	171	200	134	199	230	198	304	395
	%	0,6	0,6	1,1	1,0	1,1	1,3	1,5	0,9	1,4	1,5	1,3	1,9	2,4
Borehole off-site/ communal	N	300	297	273	199	248	209	177	183	165	189	199	229	267
	%	2,8	2,6	2,3	1,6	1,9	1,6	1,3	1,3	1,1	1,3	1,3	1,4	1,6
Flowing water/ stream/river	N	606	519	390	406	442	507	433	374	336	382	420	379	366
	%	5,6	4,5	3,2	3,3	3,4	3,8	3,2	2,6	2,3	2,5	2,7	2,4	2,2
Stagnant water/dam/ pool	N	77	62	30	52	37	30	41	53	30	42	55	35	38
	%	0,7	0,5	0,2	0,4	0,3	0,2	0,3	0,4	0,2	0,3	0,4	0,2	0,2
Well	N	146	113	124	64	70	50	37	75	55	71	77	90	54
	%	1,3	1,0	1,0	0,5	0,5	0,4	0,3	0,5	0,4	0,5	0,5	0,6	0,3
Spring	N	208	196	158	146	188	119	208	172	191	143	148	186	166
	%	1,9	1,7	1,3	1,2	1,5	0,9	1,5	1,2	1,3	0,9	0,9	1,2	1,0
Other	N	28	17	24	26	32	59	75	82	70	143	105	103	143
	%	0,3	0,2	0,2	0,2	0,3	0,4	0,5	0,6	0,5	1,0	0,7	0,6	0,9
Subtotal	N	10 806	11 413	12 087	12 409	12 830	13 303	13 731	14 172	14 620	15 107	15 601	16 122	16 662
	%	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Unspecified	N	8	12	20	76	55	0	0	1	11	0	0	0	0
Total	N	10 814	11 425	12 107	12 485	12 885	13 303	13 731	14 173	14 631	15 107	15 601	16 122	16 662

The statistics, however, vary according to region and metropolitan areas, as illustrated in Figure 2-13 and Figure 2-14, respectively. Although 88.8% of South African households had access to piped water in 2016, only 75.1% of households in Limpopo, and 75.7% of households in Eastern Cape had access. Access to water on the premises, off-site, or on-site, was most common in the City of Cape Town (99.7%), Nelson Mandela Bay and Buffalo City (both 99.2%), and the City of Johannesburg (99.1%). The City of Tshwane scored the worst of the metropolitan areas with 94.5% access to water on premises [StatsSA, 2017]. The availability criterion for water also refers to water supply interruptions.



	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
WC	98,9	98,9	99,2	98,5	99,4	98,0	98,7	99,6	98,8	99,5	98,9	98,7	98,9	99,2	98,7
EC	56,3	59,5	63,5	68,8	70,4	74,7	70,7	74,7	74,7	75,5	79,0	80,5	78,5	74,9	75,7
NC	92,5	96,2	93,2	95,4	95,3	94,7	90,5	95,8	94,1	96,2	95,6	96,3	95,8	96,5	96,1
FS	95,6	97,2	95,1	97,0	97,4	96,3	97,6	95,2	97,0	96,8	96,7	96,0	95,3	96,1	93,0
KZN	75,8	78,5	79,6	81,7	81,3	83,2	81,8	83,8	83,8	83,7	87,3	86,2	86,5	84,2	83,3
NW	85,7	90,4	88,5	87,1	90,7	89,6	89,9	87,9	91,0	91,2	91,1	88,4	87,2	86,1	86,8
GP	98,6	98,9	98,8	98,0	98,0	97,2	97,1	98,1	97,2	97,8	97,3	95,9	96,4	97,7	97,5
MP	90,6	91,5	88,2	89,9	88,9	88,4	88,2	87,3	88,0	87,5	87,5	86,8	87,1	85,5	85,3
LP	73,9	79,1	75,4	77,7	80,6	83,4	82,5	80,9	84,0	82,8	80,1	77,5	79,6	78,8	75,1
SA	84,9	87,0	86,9	88,1	88,9	89,5	88,8	89,6	90,0	90,3	90,8	89,9	90,0	89,4	88,8

Figure 2-13: Percentage of South African households with access to piped or tap water in their dwellings, off-site or on-site by province, 2002-2016 [StatsSA, 2017: p. 36]

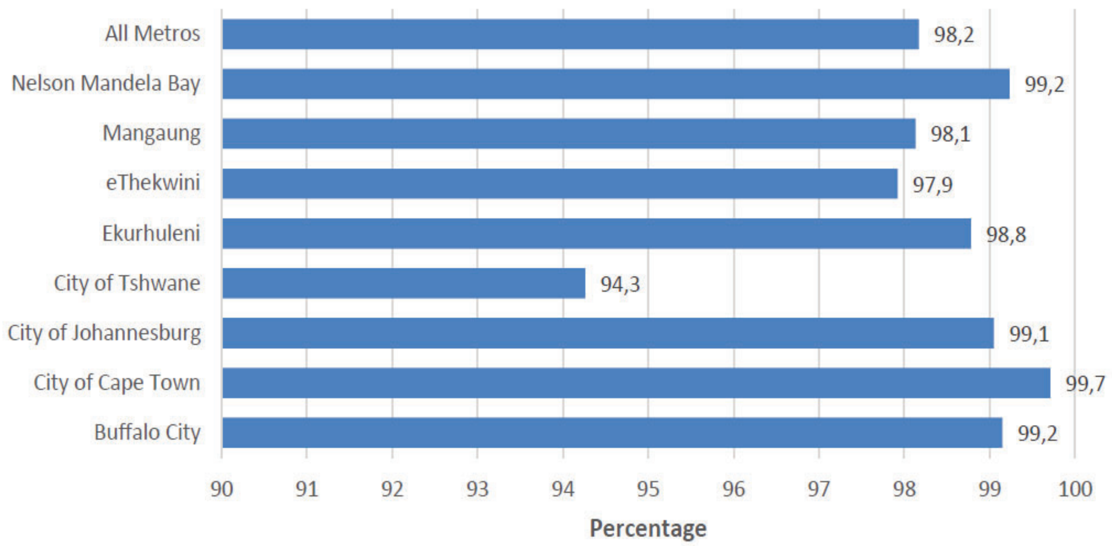
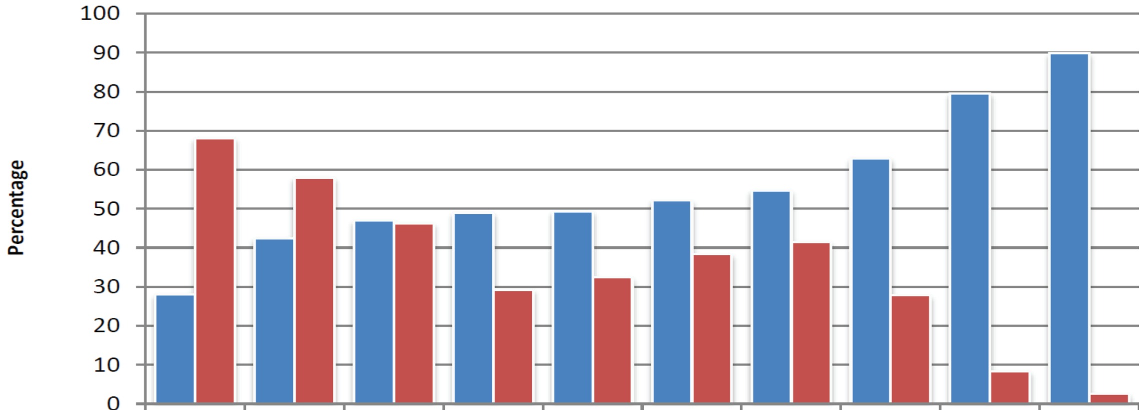


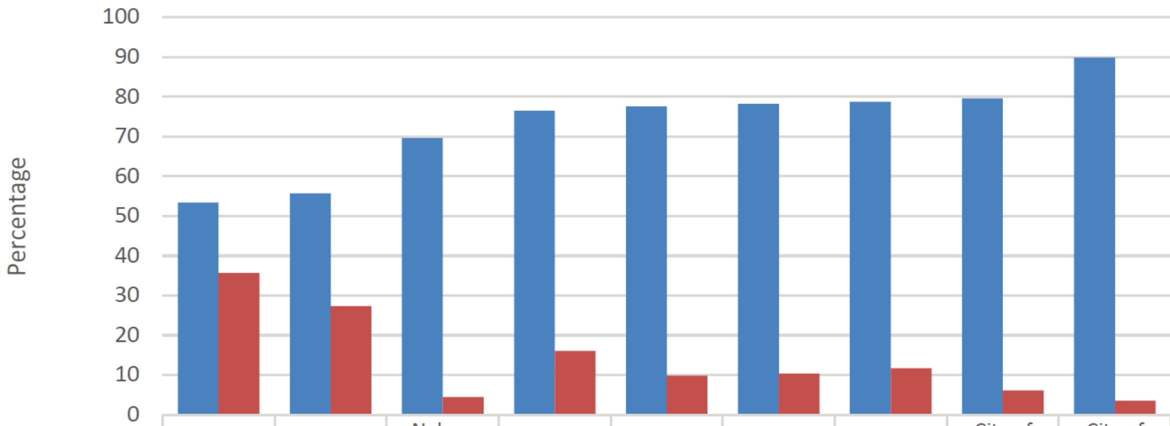
Figure 2-14: Percentage of South African households with access to piped or tap water in their dwellings, off-site or on-site by metropolitan areas, 2016 [StatsSA, 2017: p. 38]

The 2016 GHS covered the extent to which households that received water from a municipality had reported, over the 12 months before the survey, interruptions that lasted more than 2 days at a time, or more than 15 days in total during the whole period [StatsSA, 2017]. As illustrated in the red bars in Figure 2-15, households in Limpopo (68.1%) and Mpumalanga (58.0%) consistently reported the most interruptions, while Western Cape (2.5%) and Gauteng (8.3%) experienced the least interruptions. More than one quarter (27.8%) of South African households reported some dysfunctional service with their water supply in 2016 [StatsSA, 2017]. The red bars in Figure 2-16 provide the data for water interruptions reported in the various metropolitan areas. The blue bars in Figure 2-15 and Figure 2-16 refer to the quality of the service received (not the quality of the water as such). Nationally, 63.0% of households rated the quality of water-related services they received as ‘good’ in the 2016 GHS. Satisfaction has, however, been dropping steadily since 2005, when 76.4% of users rated the services as good [StatsSA, 2017].



	LP	MP	NW	FS	NC	KZN	EC	SA	GP	WC
Quality	28,0	42,4	47,0	49,0	49,4	52,1	54,7	63,0	79,5	89,8
Interruptions	68,1	58,0	46,3	29,3	32,5	38,4	41,5	27,8	8,3	2,5

Figure 2-15: Percentage of South African households rating the quality of water services provided by the municipality as good, and those that reported water interruptions by province, 2016



	Mangaung	Buffalo City	Nelson Mandela Bay	eThekwini	City of Tshwane	All Metros	Ekurhuleni	City of Johannes-burg	City of Cape Town
Quality	53,4	55,7	69,6	76,5	77,5	78,2	78,7	79,6	89,8
Interruptions	35,7	27,3	4,4	16,0	9,8	10,4	11,7	6,1	3,5

Figure 2-16: Percentage of households rating the quality of water services provided by the municipality as good, and those that reported water interruptions by Metropolitan areas, 2016

In general, the provinces in which interruptions were more frequent were less likely to rate water service delivery as ‘good’. In Limpopo 68.1% of households reported having had interruptions while only 28.0% rated water service delivery as ‘good’. The same applies to metropolitan areas. Metros in which households reported the highest quality generally reported the fewest interruptions. In 2016, 3.5% of households in Cape Town reported water interruptions while 89.8% rated the quality of water as ‘good’. By comparison, more than one third (35.7%) of households in Mangaung reported water interruptions while only slightly more than one half (53.4%) rated the water quality as ‘good’ [StatsSA, 2017].

2.4.3.1.2 Water Quality

Households’ perceptions regarding the quality (acceptability) of drinking water are presented in Table 2-18. Dissatisfaction with the quality of drinking water was most common in Eastern Cape, Free State and Mpumalanga in 2016, while households in Western Cape and Gauteng were much more content.

Table 2-18: Perceptions of households regarding the quality of the water they drink per South African province, 2016 [StatsSA, 2017: p. 42]

Perception	Statistic (numbers in thousands)	Province									
		WC	EC	NC	FS	KZN	NW	GP	MP	LP	RSA
Not safe to drink	Number	29	279	30	114	261	107	133	161	44	1 160
	Percentage	1,6	15,9	9,2	12,4	9,3	8,6	2,7	13,1	2,8	7,0
Not clear	Number	45	217	36	145	261	134	128	161	56	1 182
	Percentage	2,5	12,4	10,9	15,8	9,3	10,7	2,6	13,0	3,6	7,1
Not good in taste	Number	54	293	35	111	264	143	141	178	123	1 342
	Percentage	3,0	16,7	10,6	12,1	9,4	11,4	2,9	14,4	7,8	8,1
Not free from bad smells	Number	51	165	29	135	260	112	127	131	93	1 103
	Percentage	2,8	9,4	8,8	14,7	9,2	9,0	2,6	10,6	5,9	6,7

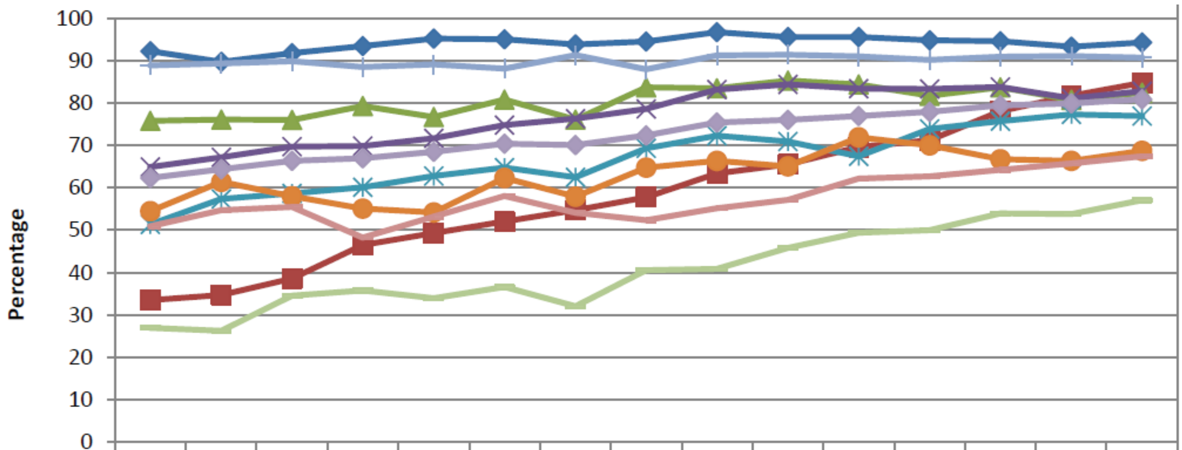
The total used as the denominator to calculate percentages excluded unspecified responses on the quality of water.

2.4.3.2 *Sanitation*

2.4.3.2.1 Availability

Figure 2-17 illustrates the estimated percentage of South African households per province that had access to improved sanitation facilities according to the GHS of 2016 [StatsSA, 2017]. The criteria used in the GHS for improved facilities are similar to that of the JMP for improved sanitation (see section 2.3.4.1), and include flush toilets connected to a public sewerage system or a septic tank, and a pit toilet with a ventilation pipe. Figure 2-18 illustrates the percentage of households that have access to improved sanitation by Metropolitan areas in 2016. The majority of households in the City of Johannesburg (95.5%) and Nelson Mandela Bay (92.8%) had access to improved sanitation facilities, while households in the City of Tshwane (82.9%) and eThekwini (83.0%) were the least likely to have access to improved sanitation. Nationally, the percentage of households without sanitation, or who used bucket toilets decreased from 12.3% to 4.2% between 2002 and 2016 [StatsSA, 2017]. Despite the improved access to sanitation facilities, many households continue to be without any proper sanitation facilities.

Figure 2-19Figure 2-19 illustrates the percentage of households that either had no sanitation facilities or that had to use bucket toilets (JMP ladder of ‘open defecation / no service’ or unimproved’ service (see section 2.3.4.1)). Nationally, the percentage of households that continued to live without proper sanitation facilities had been declining consistently, decreasing from 12.3% to 4.2% between 2002 and 2016. The most rapid decline over this period was observed in Eastern Cape (-30.3 percentage points), Limpopo (-15.4 percentage points), Free State (-11.8 percentage points) and Northern Cape (-11.3 percentage points) [StatsSA, 2017].



	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
WC	92,2	89,7	91,8	93,4	95,2	95,0	93,8	94,5	96,7	95,6	95,6	94,8	94,6	93,3	94,3
EC	33,5	34,7	38,6	46,5	49,3	52,1	54,7	57,8	63,4	65,5	69,6	71,2	78,1	81,7	84,8
NC	75,8	76,1	76,0	79,3	76,7	80,8	76,1	83,7	83,5	85,3	84,4	81,7	83,7	80,7	82,4
FS	64,9	67,2	69,7	69,9	71,7	74,8	76,3	78,6	83,2	84,4	83,4	83,3	83,8	81,1	82,8
KZN	51,4	57,4	58,7	60,1	62,8	64,8	62,5	69,3	72,3	70,9	67,4	73,9	75,7	77,3	76,9
NW	54,5	61,4	58,0	55,1	54,2	62,3	57,9	64,8	66,4	65,1	71,9	70,0	66,7	66,4	68,7
GP	88,9	89,3	89,9	88,5	89,1	88,1	91,3	88,0	91,2	91,4	91,0	90,2	90,9	91,0	90,7
MP	50,9	54,7	55,5	48,3	53,2	58,1	54,1	52,4	55,2	57,2	62,2	62,7	64,3	65,8	67,4
LP	27,0	26,3	34,6	35,8	34,0	36,6	32,1	40,6	40,9	45,8	49,4	50,0	54,0	53,8	57,1
RSA	62,3	64,4	66,4	67,0	68,5	70,4	70,1	72,4	75,4	76,0	76,9	77,9	79,5	79,9	80,9

Figure 2-17: Percentage of South African households that have access to improved sanitation per province, 2002-2016 [StatsSA, 2017: p. 43]

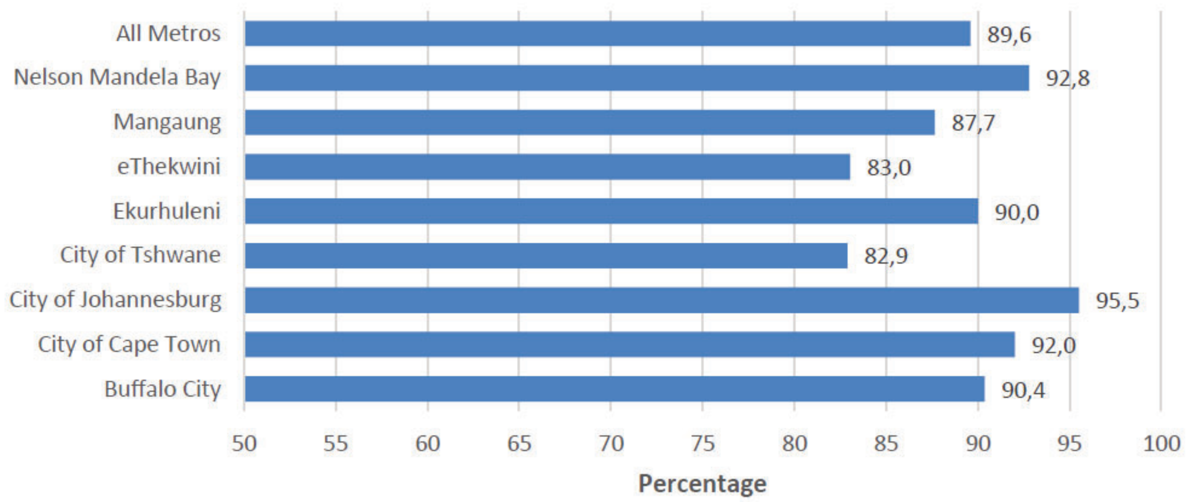
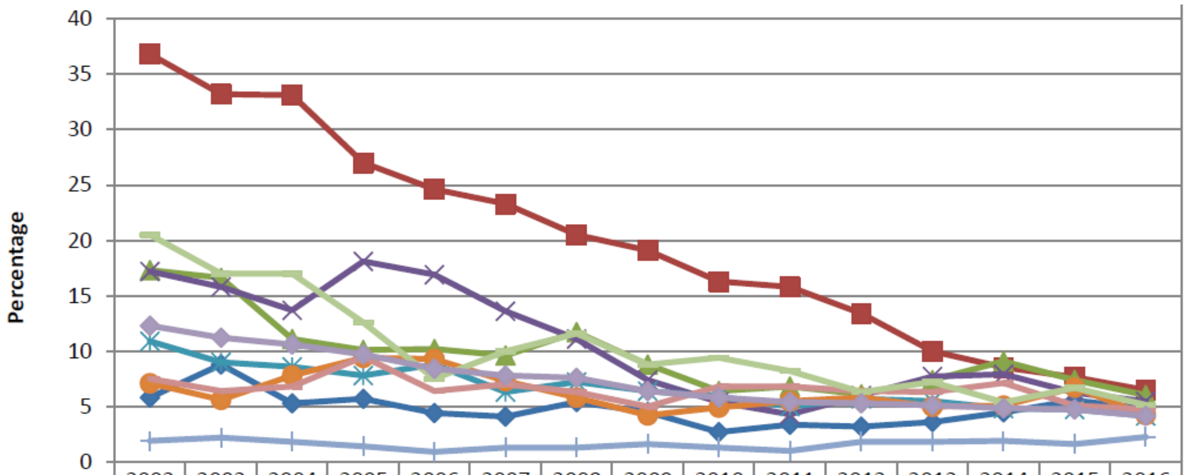


Figure 2-18: Percentage of South African households that have access to improved sanitation by Metropolitan areas, 2016 [StatsSA, 2017: p. 44]



	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
WC	5,8	8,8	5,3	5,7	4,4	4,1	5,4	4,5	2,7	3,4	3,2	3,6	4,5	5,5	4,8
EC	36,8	33,2	33,1	27,0	24,6	23,3	20,5	19,1	16,3	15,8	13,4	10,0	8,5	7,7	6,5
NC	17,3	16,6	11,1	10,1	10,2	9,6	11,7	8,8	6,4	6,8	6,1	7,4	9,1	7,4	6,0
FS	17,2	15,8	13,7	18,1	16,9	13,6	11,1	7,4	5,4	4,3	6,0	7,7	7,9	6,2	5,5
KZN	10,9	9,0	8,6	7,8	8,8	6,3	7,2	6,4	5,9	5,0	5,7	5,5	4,8	4,7	4,1
NW	7,1	5,6	7,8	9,4	9,3	7,3	5,8	4,2	4,9	5,5	5,8	5,0	5,1	6,7	4,2
GP	1,9	2,2	1,8	1,4	0,9	1,3	1,3	1,6	1,3	1,0	1,8	1,8	1,9	1,6	2,2
MP	7,5	6,4	6,8	9,5	6,4	7,0	6,3	5,0	6,8	6,8	6,4	6,3	7,1	5,1	4,7
LP	20,5	17,0	17,0	12,6	7,5	10,0	11,6	8,8	9,4	8,2	6,3	7,2	5,4	6,7	5,1
RSA	12,3	11,2	10,6	9,7	8,4	7,8	7,6	6,4	5,8	5,4	5,3	5,1	4,9	4,7	4,2

Figure 2-19: Percentage of South African households that have no toilet facility or that have been using bucket toilets per province, 2002–2016 [StatsSA, 2017: p. 44]

2.4.3.2.2 Quality

Concerning the quality of the sanitation facilities to which households had access to, Figure 2-20 outlines the extent to which households that share toilet facilities, regardless of its modality, have experienced some of the issues raised in the questionnaire. With regards to quality criteria, households complained that there was no water to wash their hands after they had used the toilet (17.3%), waiting times (16.5%), proper maintenance (12.0%) and toilets not properly enclosed (9.5%) [StatsSA, 2017].

2.4.3.2.3 Accessibility and Safety

With regards to accessibility and safety criteria, more than one fifth of households expressed concern of poor lighting (23.3%) and inadequate hygiene (20.9%), while 17.8% felt that their physical safety were threatened when using the toilet in shared facilities [StatsSA, 2017] (see Figure 2-20).

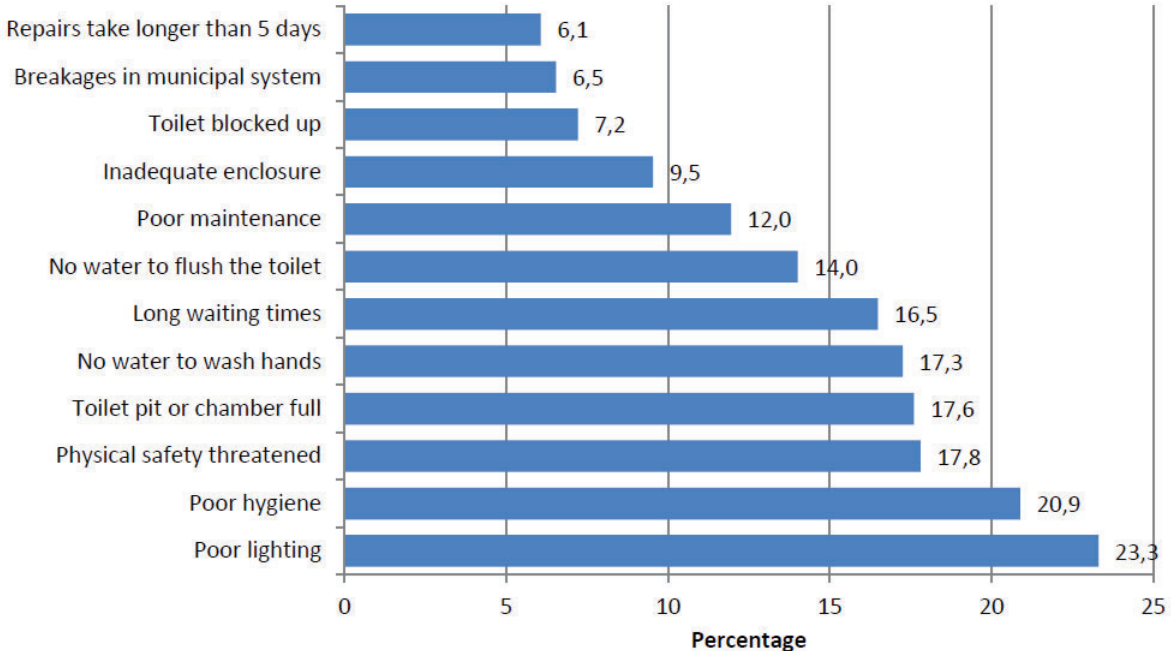


Figure 2-20: Problems experienced by households that share sanitation facilities during the six months before the survey, 2016 [StatsSA, 2017: p. 45]

2.4.3.3 *Hygiene*

The GHS [StatsSA, 2017] does not specifically address hygiene or handwashing. The only reference to hygiene is in relation to sanitation facilities where 17.6% of households complained that there was no water to wash their hands after they had used the toilet in shared facilities [StatsSA, 2017]. A 2012 study by the Water Research Commission [Wilkinson, du Tout, Mashimbye, & Cooligen, 2012] on an assessment of handwashing and hand hygiene behaviour in three sites (urban, peri-urban and rural) in the Tshwane Metro Municipality reported the following results:

- *The hand hygiene message learnt from an information source in the last month*:
  - Urban sample: Predominantly the ‘always use soap to wash hands’ message (37.5%).
  - Peri-urban sample: Predominately the ‘soap protects you from disease’ message (20.7%)
  - Rural sample (individual): The ‘clean hands to remove germs’ message.
- *The source of handwashing water for each sample site*:
  - None of the urban individuals reported an on-site/yard source of handwashing water.
  - 32% of the peri-urban sample reported using on-site/yard water supply sources for handwashing water.
  - 88% of the rural sample reported using similar sources.
- *The reported use of soap to wash hands after visiting the toilet*:
  - 86% of the urban sample
  - 14% in the peri-urban sample.
  - 33% in the rural sample.
- *The observed presence of soap at the handwashing stations*:
  - All observed urban handwashing stations had soap at the station.
  - 48% of the peri-urban stations had soap at the station.
  - 12% of the rural stations had soap at the station.
- *Reported number of critical times (see below) of handwashing with soap*:
  - All the urban individuals listed at least one of the critical times for handwashing with soap.

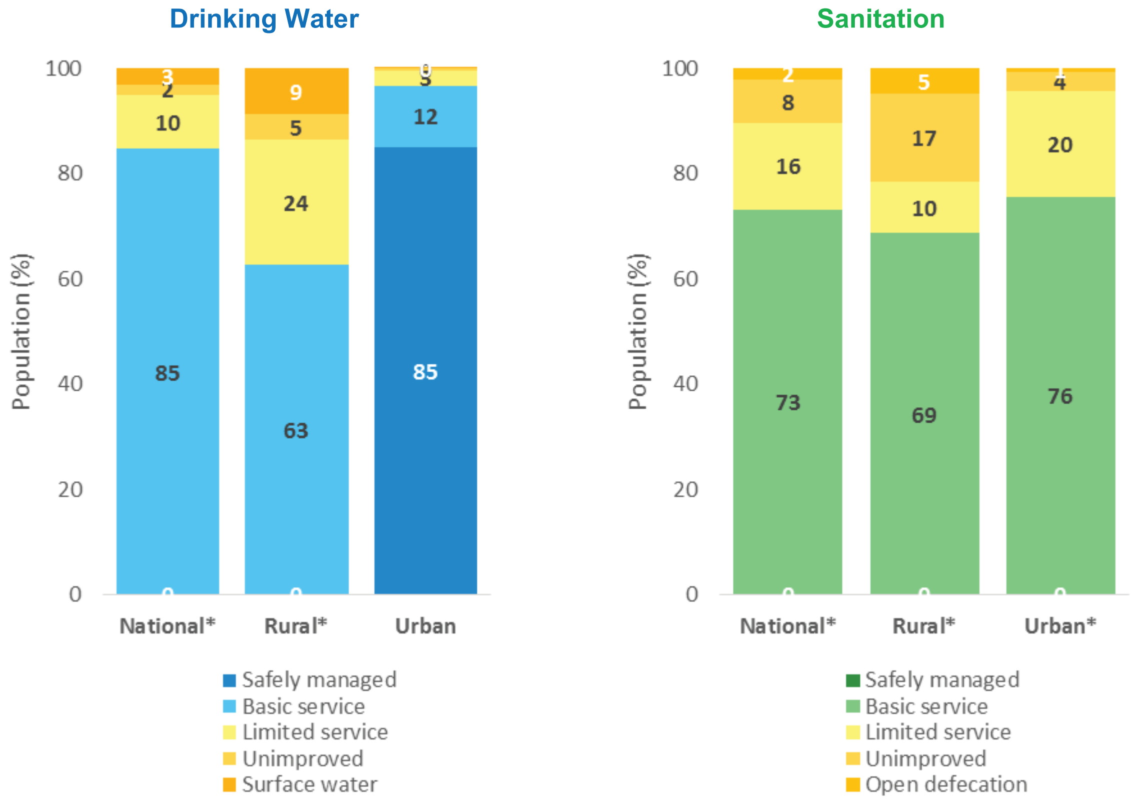
  - 14% of the peri-urban sample reported at least one critical time as a time for handwashing with soap.
  - 37% of the rural sample reported at least one critical time as a time for handwashing with soap.
- *Number of reported good hand hygiene technique activities*:
  - At least 54% of the urban sample reported all five activities of good hand hygiene technique (see description below).
  - 32% of the peri-urban sample listed all 5 activities.
  - 6% of the rural sample listed all 5 activities.

The five good hand hygiene technique activities included using water, using soap or ash, washing both hands, rubbing hand together at least three times, and drying hand hygienically [Wilkinson et al., 2012]. Critical times for handwashing included after defecation, after cleaning babies bottoms, before preparing food, before eating, before feeding children, after contact with contaminated surfaces, after handling pets and domestic animals, after wiping or blowing nose or sneezing, after handling soiled tissues, after contact with blood and body fluid, before and after dressing wounds, before giving care to an 'at risk' person, and after giving care to an infected person [Wilkinson et al., 2012].

The study concluded that the cleanliness of an individual's hands (i.e. the bacterial counts on a individuals hands) was determined by a combination of indicators of household living standards, availability and type of technologies required for appropriate hand hygiene and an individual's hand hygiene knowledge [Wilkinson et al., 2012]. The report also showed that hand hygiene interventions at the time of the study, which focused on providing basic sanitation services and the use of disease theory to promote the need for hand hygiene, focused on some, but not all, the key aspects required to improve the cleanliness of hands and hand hygiene techniques. It also indicated that hand hygiene in South Africa showed significant difference with what had been found in international literature, and that there were gaps in the local and international understanding of hand hygiene that required more research [Wilkinson et al., 2012].

2.4.3.4 *International Data on Availability of WASH Services and Practices in South Africa*

The JMP Data for South Africa for 2015 (as updated in July 2017) [WHO and UNICEF, 2017a] for drinking water and sanitation is presented in Figure 2-21. No JMP data for South Africa is available for hygiene.



South Africa	Drinking water			Sanitation			Hygiene		
	National* 2015	Rural* 2015	Urban 2015	National* 2015	Rural* 2015	Urban* 2015	National 2015	Rural 2015	Urban 2015
Safely managed	-	-	85	-	-	-	-	-	-
Basic service	85	63	12	73	69	76	-	-	-
Limited service	10	24	3	16	10	20	-	-	-
Unimproved	2	5	0	8	17	4	-	-	-
No service	3	9	0	2	5	1	-	-	-

Figure 2-21: WASH Data South Africa 2015 [WHO and UNICEF, 2017a]

Although no specific hygiene data is available for South Africa, the picture for Sub-Saharan Africa is pretty bleak, as illustrated in (see Figure 2-22) [WHO and UNICEF, 2017b: p. 19]. In 34 out of 38 African countries with data for 2015, less than 50% of the population used basic handwashing facilities.

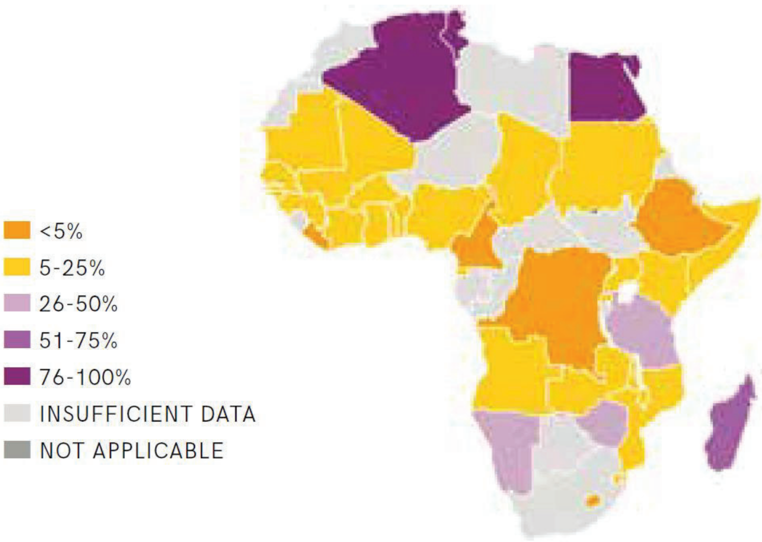


Figure 2-22: National population with basic handwashing facilities including soap and water at home in Africa, 2015 (%) [WHO and UNICEF, 2017b: p. 19]

2.4.3.5 *Data on Diseases Related to WASH*

Table 2-19 provides the WHO estimated data for all-age deaths and DALYs in South Africa in 2010 that can be linked to example diseases associated with WASH related risk factors.

Table 2-19: Deaths and DALY's attributable to WASH related causes for South Africa – WHO August 2010 estimates [WHO, 2017b]

GBD Cause	Disease	Deaths (in thousands)	DALYs (in thousands)
Water supply, sanitation and hygiene	Diarrhoeal diseases	12.3	357.0
	Intestinal nematode infections	0.0	52.2
	Protein-energy malnutrition	1.2	92.5
	Consequences of malnutrition	0.7	26.2
	Schistosomiasis	1.5	59.3
Water resources management	Malaria	0.1	2.5
Safety of water environments	Drownings	1.0	30.3
Attributable to several causes	Other infectious diseases	1.4	39.6

CHAPTER 3: THE INTERNET OF THINGS (IOT) – A GLOBAL VIEW ON ITS IMPLEMENTATION AND DEPLOYMENT

3.1 WHAT IS IOT?

The concept of the 'Internet of Things' (IoT) has been coined as far back as 1999 [Ashton, 2009]. An initial International Telecommunication Union (ITU) report published in 2005, explored the potential of IoT [ITU, 2005]. However, it is only in recent times that IoT has become a well-known (albeit not well understood) concept that is receiving attention [Panetta, 2016a]. Numerous definitions of IoT can be found in literature and on the web. For example, the European Union defined IoT as "a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network. In the IoT, 'things' are expected to become active participants in business, information and social processes where they are enabled to interact and communicate among themselves and with the environment by exchanging data and information 'sensed' about the environment, while reacting autonomously to the 'real/physical world' events and influencing it by running processes that trigger actions and create services with or without direct human intervention" [Sundmaeker, Guillemin, Friess, & Woelfflé, 2010: p. 43]. In 2015 the IEEE IoT Initiative published a document capturing numerous definitions of the IoT [Minerva, Biru, & Rotondi, 2015], indicating that a shared understanding of the concept of IoT is still being developed.

After the review, they proposed two 'neutral' definitions of IoT, one for small low complexity environments, where 'things' are uniquely identifiable, and large interconnected environments where a large number of things' can be connected:

- *Small low complexity environment*: "An IoT is a network that connects uniquely identifiable "Things" to the Internet. The "Things" have sensing/actuation and potential programmability capabilities. Through the exploitation of unique identification and sensing, information about the 'Thing' can be collected and the state of the 'Thing' can be changed from anywhere, anytime, by anything" [Minerva et al., 2015: p. 73].
- *Large interconnected environment*: "Internet of Things envisions a self-configuring, adaptive, complex network that interconnects 'things' to the Internet through the use of standard communication protocols. The interconnected things have physical or virtual representation in the digital world, sensing/actuation capability, a programmability feature and are uniquely identifiable. The representation contains information including the thing's identity, status, location or any other business, social or privately relevant information. The things offer services, with or without human intervention, through the exploitation of unique identification, data capture and communication, and actuation capability. The service is exploited through the use of intelligent interfaces and is made available anywhere, anytime, and for anything taking security into consideration" [Minerva et al., 2015: p. 74].

Through sense-making value can be derived from the data and the resulting actions (often referred to as big-data and analytics). Based on the domain of logistics, Uckelmann, Harrison, and Michahelles [2011] describe the pathway to value from IoT as *to provide the right information, in the right granularity, in the right condition, at the right time (when needed), at the right place (where the information is needed) anywhere in the network and at an appropriate price*.

For the purposes of this document, we define IoT as an *ecosystem that integrates the physical and digital via the Internet with associated computing services. Data is ingested from the physical and digital world for sense making, thus enabling the execution of contextual commands*.

As is the case with multiple definitions IoT, multiple reference architectures have been published. One example is Microsoft's IoT reference architecture [Microsoft, 2016]. This architecture is positioned to predominantly use cloud infrastructure. Similarly WSO2 presents their view of a reference architecture in Fremantle [2015]. This architecture is focused on using an aggregation/bus layer (enterprise service bus) to link device observations to services. These architectures are continuously evolving as new standards and capabilities are included. For the purposes of this report, we define a reference architecture for IoT as depicted In Figure 3-1.

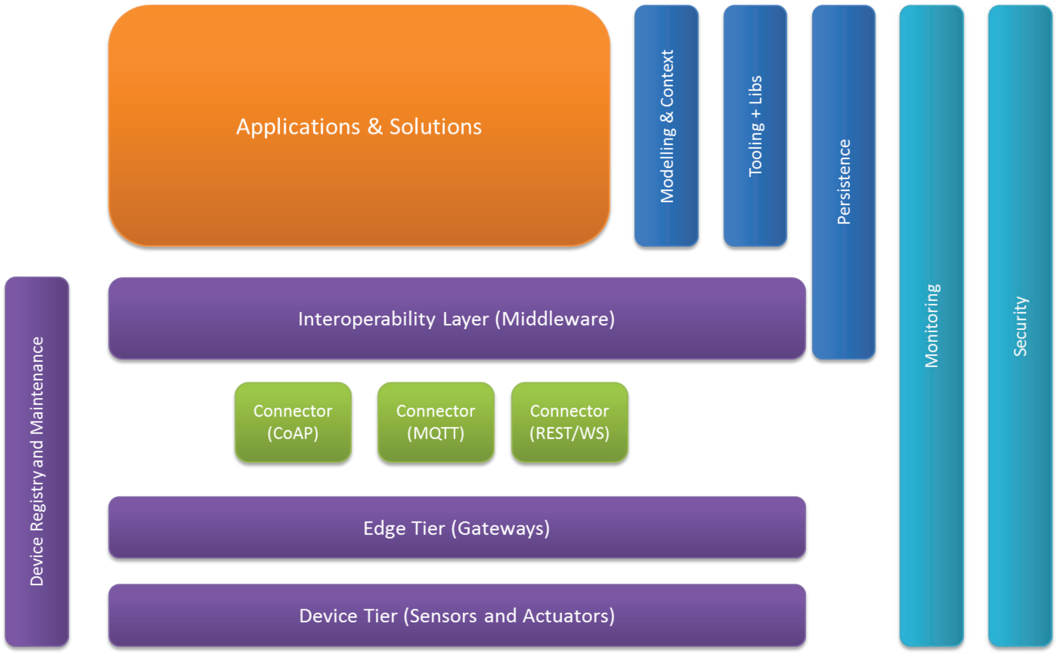


Figure 3-1: IoT Reference Architecture

A collection of devices with numerous sensors and actuators are present. These devices can communicate amongst themselves via low power local networks. The devices in turn are connected to an edge tier that hosts gateways. The gateways communicate to middleware via a typical broadband backhaul network. Popular communication protocols for this layer include the constrained application protocol (CoAP) [Internet Engineering Task Force, 2014] [Internet Engineering Task Force, 2016], Message Queuing Telemetry Transport (MQTT) [OASIS, 2015] or HTTP REST-based communication [Thomas, 2000]. A cross cutting service is responsible for the device registry and maintenance. This service provides functionality related to over-the-air updates allowing for enhancements to devices without physical access. Two more cross cutting services are responsible for monitoring of the complete installation as well as ensuring security through every tier. The interoperability layer (also referred to as the middleware layer) links applications and solutions to the data observations. One example of an open-source IoT middleware layer is Kapua [Eclipse, 2017a], which is being developed to ease the development of IoT services and the integration of heterogeneous devices and associated protocols. These applications are supported by a variety of tooling services as well as development libraries. Quite often, a big-data store is linked to the middleware layer, thus easing development of applications (removing the need for each application to host its own data store). Access to near real-time data and the ability to influence the environment opens doors for innovation by both entrepreneurs and established enterprise service providers.

Figure 3-2 presents an IoT process chain using the above reference architecture as basis. Observations are acquired via a variety of sensors. These are communicated via the Internet to backend systems (typically cloud infrastructure). A variety of services operate on the data observations. Through the services, value is introduced to society and the environment. Important to note is the bi-directional nature of the process chain. Outputs from services are fed into the processing engines, with those outputs feeding back into the physical world through actuation.

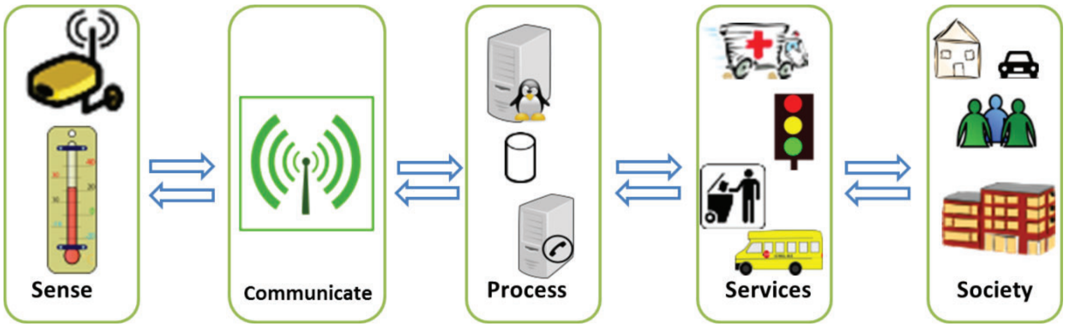


Figure 3-2: IoT Process Chain

3.2 IOT DRIVERS

IoT as concept has been known for quite some time but has only recently started to gain significant traction in both business and research communities. This can be attributed to a combination of technology and societal drivers.

3.2.1 Technology Drivers

Using our past experiences as departure point we have identified the following technology drivers contributing to the uptake of IoT:

- An increase in the number of sensor enabled Internet connected devices due to the lower cost and ubiquity of Internet connectivity.
- Smaller and more powerful devices with lower power consumption.
- Lower cost of storage and computation (e.g. as enabled by cloud infrastructure).
- The ubiquitous nature of the Internet.
- The prevalence and access to masses of data.
- Recent developments in data science (analytics and visualisation) enabling sense making from the acquired data.

These drivers are often equated with well-known 'Internet laws' such as Moore [1965], Kryder [Water, 2005] and Metcalfe [2013]. Moore's law states that the computing power for processors will double every two years, Kryder states that the density of hard drives will double every 13 months, while Metcalfe states that the value of a network grows as the square of the number of its users.

3.2.2 Societal Drivers

Society is continuously evolving with associated new or increasing needs. From our experiences over the years we have identified the following:

- To improve the quality of life.
- To know more and make better decisions.

- To feel safer and be healthier.
- To reduce cost and waste and make better use of our resources.
- To improve efficiencies by being more accurate and subsequently faster.
- To predict when a specific action is required.
- To increase sales.

Through the progress in IoT technologies, society is empowered to address needs as described above.

3.3 VALUE OF IOT

Numerous studies have been conducted with the aim of extracting the value of IoT. These studies (and the associated reporting) often focus on the financial/economical return when implementing IoT. As an example, a report by McKinsey Global Institute [Manyika et al., 2015] estimates that the economic value of IoT can be as much as $3.9 trillion to $11.1 trillion per year in 2025. An initial study by Fleisch [2010] described the value in terms of drivers which then allows for innovative applications. In his analysis drivers are equated with an action (either directly from the device or processed and integrated with other value add data), which results in value to an end-user through an application. As depicted in Figure 3-3, a 'simple trigger' from a thing, which contains the identity (ID) of the thing that was triggered, can be used in retail for a 'self-check-out' application. More complex value chains are consequently identified. A user context can be influenced by an action resulting from the processing of multiple data streams (big data analytics). In his analysis 'mind changing' feedback can be used in the insurance industry (i.e. a vehicle regularly travelling too fast, which raises the risk profile associated with the driver). It is often quite valuable to think of the value that can be obtained from a specific observation in a domain, when thinking along the lines of these drivers as depicted in Figure 3-3.

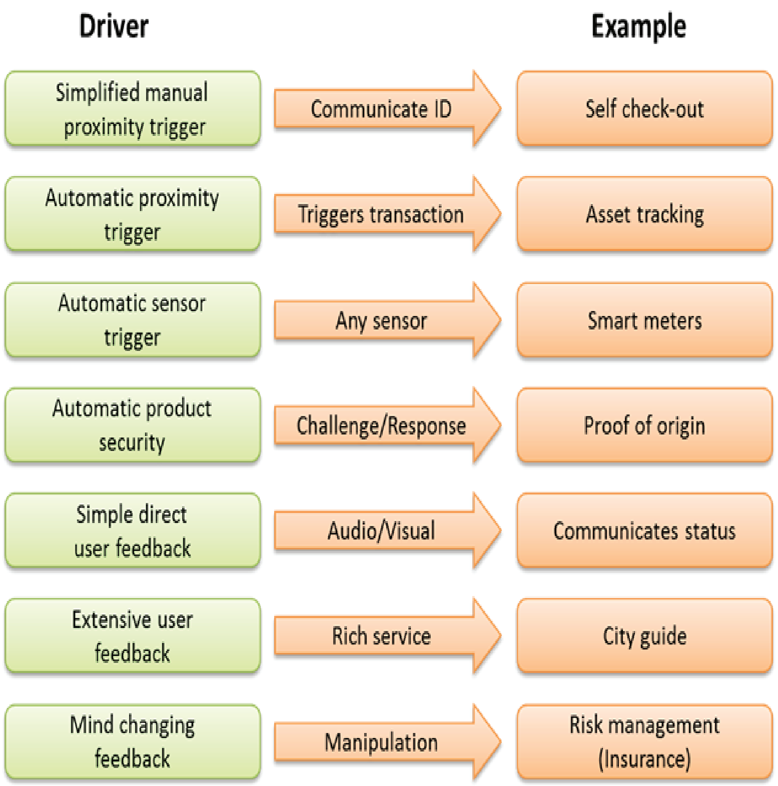


Figure 3-3: Value drivers for IoT (figure derived from table presented in Fleisch [2010])

This is in contrast to broad views of where IoT can be (and is) applied. A key value proposition from IoT is access to (better) data. With the introduction of sensors better understanding through the data of an environment can be obtained. For example, access to data can allow for ‘evidence-based’ decision making to formulate policies, or to make better decisions (smarter sense-making through analytics) that can positively influence the environment and society [Chui, Markus, & Roberts, 2010; Hedrick, 2016].

3.4 IOT DEPLOYMENT

3.4.1 Domains

Traditionally IoT has been associated with applications covering a multitude of domains. Vermesan and Friess [2014], for example, highlight application of IoT in areas such as:

- Cities
- Transport
- Buildings
- Energy
- Industry
- Health.

3.4.2 Application areas

McKinsey Global Institute has broken down the IoT areas of application into the following settings, with examples [Manyika et al., 2015: p. 3]:

- *Human*: “Devices (wearables and ingestibles) to monitor and maintain human health and wellness; disease management, increased fitness, higher productivity”.
- *Home*: “Home controllers and security systems”.
- *Retail environments*: “Stores, banks, restaurants, arenas – anywhere consumers consider and buy; self-checkout, in-store offers, inventory optimization”.
- *Offices*: “Energy management and security in office buildings; improved productivity, including for mobile employees”.
- *Factories*: “Places with repetitive work routines, including hospitals and farms; operating efficiencies, optimizing equipment use and inventory”.
- *Worksites*: “Mining, oil and gas, construction; operating efficiencies, predictive maintenance, health and safety”.
- *Vehicles*: “Vehicles including cars, trucks, ships, aircraft, and trains; condition-based maintenance, usage-based design, pre-sales analytics”.
- *Cities*: “Public spaces and infrastructure in urban settings; adaptive traffic control, smart meters, environmental monitoring, resource management”.
- *Outside*: “Outside uses include railroad tracks, autonomous vehicles (outside urban locations), and flight navigation; real-time routing, connected navigation, shipment tracking”.

3.4.3 The smart cities concept

Smart cities were one of the first areas of mass IoT deployment. It is believed that the digital technologies drive better public services for citizens, better use of resources and ensures reduced impact on the environment. Services related to transport (parking), resource management related to energy and water (smart metering) is becoming commonplace.

3.4.4 Industrialisation of IoT

Application of IoT in factories and worksites, often referred to as 'Industry 4.0' (fourth industrial revolution) [MacDougall, 2014] is also being adopted rapidly. The promise of IoT's 'big data and analytics' function for predictive maintenance drives the uptake as a significant cost and operational saving becomes possible.

3.4.5 Application of IoT In WASH Management

As described in the previous sub-sections, IoT have been (and are) increasingly applied to numerous domains. However, even though reference is made to smart metering for energy and water, the concept is mostly used for billing purposes, and IoT for WASH (as defined in this report) has not featured prominently. Viewing IoT in relation to the United Nation's crosscutting criteria for WASH (see section 2.3.2) several links and associations can be made:

- Participation: Using mobile-based technologies linked to sensors, communities can contribute to improving their own WASH context.
- Accountability: Armed with the data from the community-based IoT solution, entities responsible for maintenance and planning can make evidence-based decisions.
- Impact: Valid and justifiable choices have a higher probability for impact.
- Sustainability: With the inclusion of communities and the ability to solve that community's specific challenge, the probability of a sustainable intervention is higher.

Several large bodies and companies are active in the WASH sector. Most prominent of these are the European Commission (e.g. ICT4Water Cluster [2017]) and the ITU (e.g. Biggs et al. [2016]). Multinationals (e.g. Google [Charity: Water, 2012]) and academia (Oxford University, for example Smith School of Enterprise and the Environment [2014]) also have a footprint through research and innovation initiatives. Non-government organisations (NGOs) such as the Toilet Board Coalition [2016] are also active in the WASH domains. In the following sections, we provide information on some of the entities active in the various WASH domains. In each of the sections, we describe insights obtained from the case studies or examples. Quite often, the trials were implemented using the technologies from the entities that are highlighted and the study are referred to by e organisation/entity name. Some of the examples also spans across the individual WASH sub-sectors. Only examples specifically related to water and sanitation were found, and no hygiene only study is therefore described.

3.5 APPLICATION OF IOT IN WATER MANAGEMENT

3.5.1 Smart Water Resources Management in Cities

Currently the *improved water* industry lacks an adequate holistic understanding of water supply, its flow and its use. There is a need for improved data collection in the entire water value chain, and the transformation of such data to generate actionable information. Many experts believe that technology and smart water management are the only real way to improve financial sustainability within in the context of reduced capital and increases in operational running costs of current utilities [Department for Business Innovation and Skills, 2013]. According to a report by the ITU-T Focus Group on Smart Sustainable Cities [Gemma, Sang, McIntosh, & Ospina, 2014], the following categories of activities exist in smart water management:

- Data acquisition.
- Data dissemination.
- Modelling and analytics.

- Data processing and storage.
- Management and control.
- Visualisation and decision support.
- Sharing of information to citizens and technical services.

A correlation exists between these categories and the architectural concepts. However, for the smart water management system to be regarded as a fully-fledged IoT solution aspects related to security, device management and monitoring amongst others are lacking.

In the case of *improved water*, a smart water system within the context of the water utilities market can be defined as a fully integrated system in which "technology manages the distribution and management of water resources, where advanced water treatment is present, where demand-side efficiency is enabled and where products improve water efficiency and food production" [Department for Business Innovation and Skills, 2013: p. 26]. This aligns with the ITU definition of smart water management that refers to the use of integrating ICT products, solutions and systems for water management (including storm water management) and sanitation within a city context. In such a fully integrated system, the products and services offered will enable the water utilities and its customers (business and households) to [Department for Business Innovation and Skills, 2013; Gemma et al., 2014]:

- Continuously and remotely monitor and diagnose problems and optimise performance:
    - Take pre-emptive measures to manage maintenance.
    - Reduce supply disruptions and improve customer service.
- Conserve water by:
    - Managing water consumption more proactively and maintain price stability.
    - Providing users with intelligent information, which enables them to make choices about their water usage.
    - Comply with wastewater regulation.

Champanis et al. [2013], reporting on the state of use of ICT solutions for the water sector in South Africa, also refers to smart water management. The report notes that in 2013 literature related to ICT and its application to the water sector was quite limited. In the report, smart water management systems are described by referring to a water meter, able to communicate water utilisation at regular intervals, fitted to an existing water distribution network. Data acquired through the system can potentially be used to track trends and identify abnormalities (e.g. a sudden period of very high water utilisation might be an indication of a leak in the system). The use of mobile phones for information transfer and to facilitate services is another notable finding of the study. The mobile phone is seen as a possible key enabler for mobile payments for water. It is important to note that the study looked at the broader ICT sector and not IoT specifically. However, a smart water management system, as described, can be regarded as an IoT solution for water resource management.

Figure 3-4 provides an overview of the smart water value chain in the context of *improved water* in mostly urban city environments*, indicating* where 'smart technologies' could be utilised. It illustrates the water cycle from its source, initial treatment, delivery to domestic and industrial users, and its final treatment before it is discharged back into the water system (the agricultural sector is not shown in this figure) [Department for Business Innovation and Skills, 2013].

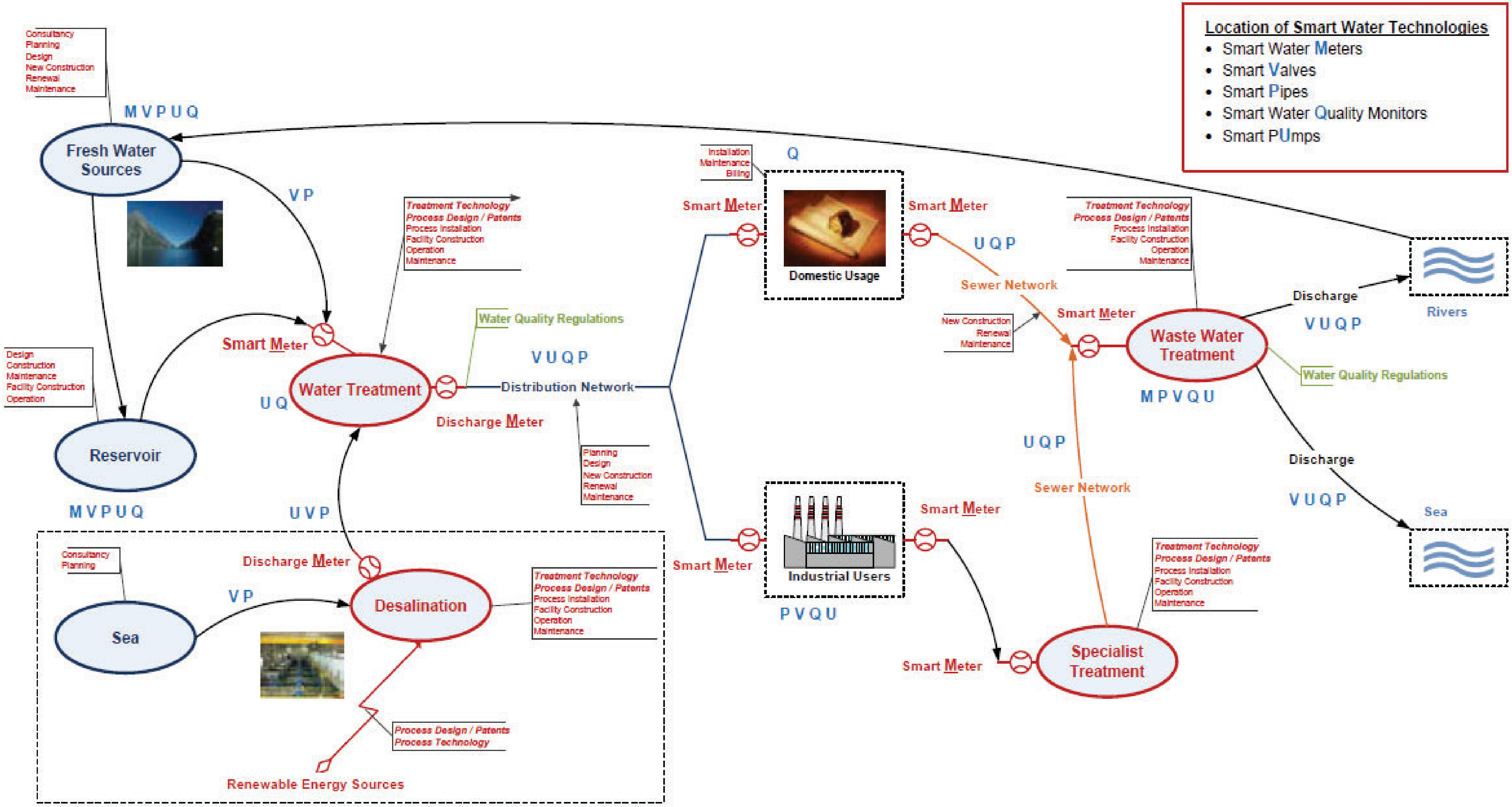


Figure 3-4: Smart Water Value Chain [Department for Business Innovation and Skills, 2013: p. 38]

3.5.2 Selected examples of smart water management studies

3.5.2.1 *ITU-T*

In the ITU-T Focus Group on Smart Sustainable Cities report "*Smart water management in cities*" a number of ICT (IoT) related solutions to water management are presented [Gemma et al., 2014]. The report identifies ICT enabled advantages for smart water management, such as improvements in water quality and reliability, lowering of operational costs, open-data sharing, leak identification and elimination, green water and increased customer choice and control.

3.5.2.2 *ICT4Water*

The ICT4Water Cluster [2017] website acts as a hub for all European Commission funded research projects related to ICT and Water management. A roadmap report published by the cluster captures trends related to ICT and water management and identifies activities that need to be addressed to enable a SMART water market [Glenisson & Wojcieszko, 2016].

3.5.2.3 *Examples from Kenya*

Kenya has been proactive with the use of ICT in water management. Although not 'smart' in the true sense of the word, the projects in general focus on using mobile phones for data collection, and as a result citizen inclusion. Perusing a case study from the World Bank the following projects were analysed [Ndaw & Mwangi, 2015]:

- Water Regulation Information System (WARIS): A web-based tool for performance assessment of water service providers. The water service providers are measured according to existing national key performance indicators.
- MAJIDATA: Collects data on urban poor water and sanitation service delivery. It provides baseline data for unplanned urban settlements. This data enables reliable planning. Data is stored on a traditional web system.
- MAJI Voice: An application built for the water service providers to coordinate and resolve consumer complaints. It communicates via USSD or SMS into a web backend. The application also provides a regular web interface for consumers. An important aspect to note is that the consumer carries the cost of communication from the consumer to the water service provider. Therefore, there is a trade-off in improved service delivery versus the cost of initiating that service.
- Jisomee Mita: Enables online billing to improve customer payments. A customer can send his water reading via SMS to the water service provider. The water service provider responds with the current outstanding amount. The customer can settle the debt using mobile payment platform.
- Mobile field assistant: Through the use of smart phones the task of reading the current utilisation of water by meter readers is improved. The reader uses the smart phone to collect information on the location of households, meter readings and geo-references. Meter readers' effectiveness is also improved by using smarter route planning communicated via the smart phone.
- Mmaji: Using mobile phone information regarding the availability and price of water is communicated. This empowers the customer to identify the most cost-effective water vendor.
- WASPA MIS: The water service providers association in Kenya evaluates the performance of water service providers by evaluating the performance against a set of KPIs. The tool used is quite primitive as it is based on an Excel spreadsheet.

It should be noted that there is no, or only limited, interoperability between the various systems described above. Furthermore, the use of a mobile device is prevalent to communicate information from and to the customer. No in-situ sensing and communication of those observations are being done. A key aim of the technologies was to improve billing, and very importantly to extract relevant and reliable data.

3.5.2.4 *Examples from Tanzania*

According to a Tanzania case study by the World Bank, ICT tools have been developed to acquire and integrate data and to disseminate information [Ndaw & Welsien, 2015]. The potential of using smart phones to enable data collection and to disseminate information has been recognized. The Dar es Salaam Water and Sewerage Corporation (DAWASCO) has been driving ICT solutions, specifically to improve revenue collection through e-payment. A management information system using mobile applications has been used to collect information from water treatment plans (levels and maintenance). The data collected by operators are communicated to a normal web system. With reference to the water value chain in South Africa, illustrated in Figure 4-2, and the sanitation value chain in South Africa, illustrated in Figure, all these examples are limited to improved water resources and in most cases individual water connections and/or safely managed or improved sanitation.

3.5.3 **Other examples of IoT use in water management**

This section describes case studies or examples of the use of IoT outside of the smart water management sector, and in most cases outside the *improved water* category.

3.5.3.1 *Charity: Water*

Charity: Water [2017] is a non-profit organisation with the mission to bring clean and safe drinking water to people in developing countries. The organisation is dependent on donor funding and has been recognised by Google through its Global Impact Awards. The charity has a drive to install a large number of low cost sensors to determine the state of wells and if the wells need to be fixed (in addition to capturing the location of the wells). The sensors transmit real-time data on the condition and flow of water at instrumented wells. The sensors contain an aspect related to 'edge' computing and analytics as it 'learns' the normal operational parameters and has the ability to identify an anomaly which is then reported. The sensors are linked to a software platform referred to as 'Dispatch Monitor' where the information from the sensors is presented in a visual form. An innovative support model is associated with the installed sensors. Local members of the community ('mechanics') are provided with skills to maintain the water supply [Charity: Water, 2017].

3.5.3.2 *OxWater*

OxWater is a spinout company from Oxford University [OxWater, 2017]. It has developed and tested an innovative system using accelerometers in water lever hand pumps [Thomson et al., 2012]. The system measures the utilisation and status of lever hand pumps at specific water points. The system provides immediate data that allows for maintenance and planning. The system can be regarded as a fully functional IoT solution as it also combines machine learning algorithms, operating on the acquired data, to predict water use, potential failures and to estimate shallow aquifer depths [Colchester, Marais, Thomson, Hope, & David Clifton, 2017].

3.5.3.3 *Akvo.org*

Akvo [2017] is a not-for-profit organisation focusing on international development and country governance. Its aim is to improve management for numerous domains including that of water, sanitation and health specifically for disadvantaged populations. They approach this task by following an IoT approach of using open-source software linked with sensors. Even though the tools are open-source, annual support can be obtained through a licensing model. Akvo provides a suite of tools that includes [Akvo, 2017]:

- Akvoflow: Uses a smart phone to collect geo-spatial data (surveys). Linked with a visualization dashboard anomaly can be identified and shared with others.
- Akvolumen: is A data aggregator and transformation tool. With the tool, heterogeneous data can be sourced and transformed into formats that allow for enhanced decision making as rapid visualization with its dashboards.
- Akvorsr: A content management platform enabling better coordination of activities and with the ability to monitor and share results.
- Akvosites: A hosted solution where project and other results can be shared.
- Akvo-caddisfly: A smart phone solution for in-situ water quality measurements. The measurement is done through hardware attachments to the smart phone with the data observations shared with a backend data aggregation system. The hardware attachments measure fluoride, and salinity, and perform strip tests such pH, nitrate, nitrite, phosphates, iron and chlorine.

The Akvo solutions can be used across the water value and the sanitation value chain if the necessary technical connections to do so are available and active.

3.5.3.4 *SWEETSense*

SweetSense Inc. [2017] is a spin-out company of Portland State University in the USA. It is active in the development sector using sensors and appropriate backend systems (a full IoT solution) and has as its mission:

"*to improve transparency, accountability, and cost-effectiveness of remote water, energy, and infrastructure projects to improve health and quality of life. We fix the Internet of Broken Things®*".

SWEETSense has developed an in-situ IoT smart edge device that can be installed in the community. The device can be fitted with a number of different sensors (depending on the application domain, including water treatment, sanitation, energy and infrastructure). Communication from the device to the, in-house developed, cloud enabled IoT back-end platform can be facilitated through different communication channels (cellular or satellite). The device has low power consumption and can be installed rapidly and with minimal effort. SWEETSense uses the system to improve service delivery, in addition to measure the effectiveness of interventions in developing countries. The SWEETSense offerings can be applied across the water and sanitation value chains.

3.5.3.5 *AYYEKA*

Ayyeka [2017] has created a set of technologies that has been industrialized (e.g. hardened to better cope with harsh environments and situations). These technologies are referred to as AYYEKA's Wavelet for remote monitoring. Solutions that can be created include water network monitoring (e.g. pressure and leak detection, and general status of the water network), as well as wastewater management (e.g. to detect for possible sewer overflow events). It is important to highlight that the solutions are hardened, an aspect that is critical to ensure operation in harsh conditions. Similar to the SWEETSense offering, AYYEKA technologies can be applied across the value chains.

3.5.3.6 *Examples from Liberia*

In a study conducted by the World Bank, for Liberia an ICT application “AkvoFLOW” for water supply is described (Section 3.5.3.3) [Ndaw & Niyungeko, 2015]. AkvoFLOW maps water supply systems using field surveys via smartphones. This application enables handheld field data collections. The application links the geo-spatial location to a specific water point. Furthermore, the application can upload photos as captured by the smart phone to provide a visual of the current status. The data is uploaded to a central database from where a dashboard provides access to the collected data. The data is collected and kept on the phone (in off-line fashion) until access to the Internet can be established and the data uploaded to the central server. As is the case in the analysis presented in Section 3.5.3.3, the ICT applications provides for better data, which in turn enables larger transparency and subsequently enables better decisions by server providers and government. However, these are facilitated by humans and do not include in-situ or other typical IoT aspects.

3.5.3.7 *Examples from Uganda*

In a study by the World Bank two projects have been identified in Uganda [Ndaw & Mutono, 2015]:

- E-water payment system: Customers receive and can settle their water bills via their mobile phones.
- Mobiles for Water: This project was supported by the Netherland NGO SNV. Mobile phones were used to map the water points and to report water point problems using software developed by Makarere University. The types of water sources available include shallow wells, deep boreholes, protected springs, yard taps and public tap stands. Mechanics were empowered to assess and report the status of hand pumps via the mobile phone software. In a report on the Mobiles for Water project, a number of challenges were identified [Wilbord & Ali, 2013].
    - Water points are identified and marked with stickers, but these stickers were damaged by the elements.
    - Back-end services did not have reliable uptimes or access.
    - Mobile phones were used to install the bespoke software and to collect the data. However, the software configurations were often lost due to SIM swaps by the mechanics.
    - The project implementers are dependent on information from the users. The users did not always share this information.
    - Users preferred to make voice calls rather than sending SMSs.

This example runs across the water value chain. Although mobile phones used for data collection and improved billing are at the forefront of ICT use in Uganda, no IoT installations were operational at the time of this study.

3.5.3.8 *Examples from Kenya*

In Kenya, Upande (upande.com) is developing an open-source system WashMIS (Water Sanitation Hygiene Management Information System [Upande, 2017]). The system uses sensors to measure water flow, pressure as well as water levels, which are linked to billing data with the purpose of improving service delivery. Even though the system is built using an open-source model, access to it is via a licensing model. The example is linked to improved water resources.

3.5.3.9 *Examples from Tanzania*

In the Tanzanian case study by the World Bank [Ndaw & Welsien, 2015], reference is made of one ICT (IoT) application, called ‘mwater’. The project aims to measure and communicate the water quality of a water point. The quality is measured using an in-field test kit for microbiological tests, with results communicated via a mobile application to a back-end platform. The initial intent was to empower the local communities to conduct the in-field tests and communicate those results to the back-end server. However, the technical complexity forced the project managers to use trained staff from other existing institutions. The example application can be used across water value chain.

3.6 APPLICATION OF IOT FOR SANITATION

3.6.1 The Toilet Board Coalition

In a study by the Toilet Board Coalition [2016], trends related to using digital technologies in sanitation were presented. The key findings presented in the report were:

- Megatrends such as mobile money and IoT to date have not been exploited to its fullest potential.
- Sensors in a toilet can transform the toilet into a valuable source of health-related information. In addition, information collected from toilets can provide valuable insights into toilet usage and optimise waste collection (addressing both schedules as well as routing aspects).
- Low-income markets can benefit from using existing mobile and digital tools.
- In future innovative tools and applications will become available for multiple industries (beyond the sanitation sector).
- Some enablers are still required to exploit the potential opportunities.

3.6.2 African Examples of IoT Use in Sanitation for Rural Areas and Developing Country Contexts

3.6.2.1 *Kenya*

The Toilet Board Coalition [2016] report describes an initiative in Kenya for a 'smart' IoT enabled toilet. The technology is provided by SweetSence Inc. [2017], as described in Section 3.5.3.4. The initiative is testing the feasibility of using sensors in waterless toilets in informal settlements. The full IoT value chain is tested in this initiative. A device with a sensor, which captures data, is embedded in a toilet. This data is analysed locally allowing for local diagnostics (this basic health assessment can be communicated to a mobile smartphone). Using the device's communication channel, the data is sent to a back-end platform for further analysis. The results are accessed by health professionals, after which appropriate actions can be initiated (advice communicated back to the user's smart phone, treatment for the user facilitated, or action initiated based on early warning indicators). As a final step, the data is aggregated into a database allowing further time-based analysis. This example addresses basic/limited sanitation, as in the sanitation value chain illustrated in Figure 4-4.

3.6.2.2 *Liberia*

In the World Bank Study for Liberia [Ndaw & Niyungeko, 2015], Geospago [2017], an ICT application for sanitation is described. Geospago is a geo-spatial application used to collect data on sanitation aspects including latrine blocks, drainages and open defecation areas. It is a mobile solution, with a customisable interface, used to collect data and communicate the data to a backend service. The backend service provides a web dashboard with maps.

3.7 APPLICATION OF IOT IN HYGIENE MANAGEMENT

No examples of the use of IoT in hygiene in household, everyday life or school environments could be found.
The only example of the use of IoT in handwashing could be found in the USA, developed by GOJO Industries, the providers of Purell hand sanitizers [MyIOTLearningCenter.com, 2018]. The GOJO SMARTLINK IoT solution aims to help healthcare facilities in the USA to monitor and improve their hand hygiene compliance rates. The GOJO SMARTLINK solution connects two types of monitoring devices: an activity counter that tracks movement in and out of a specific area, such as a patient's room, and a usage sensor on each Purell dispenser. The monitors feed data to an IoT and analytics platform built on the Microsoft Azure IoT platform.

3.8 SUMMARY

The initiatives presented above can be broadly categorized into three categories:

- Initiatives to enable aspects such as billing and payment; the focus is on server-side solutions with information sourced through smart mobile devices and community involvement.
- In-situ monitoring of field equipment status, mostly hand pumps with an associated ecosystem for community-based support and maintenance.
- Minimal application of IoT to collect in-situ information, one related to water quality and a second related to 'solid waste' present in toilets.

The three identified categories by no means address the full potential of IoT if linked to the value chains in the WASH sector. It is also important to note that most of the available technologies and publications are associated with water resource management, and in the majority of cases billing. Sanitation and hygiene have not featured prominently in literature that the authors of the report were able to source in the public domain. It is fair assumption that this is most likely due to demanding challenges related to in-situ sensing and communication. For instance, it is challenging to build a robust sensor that can be installed in the field that is able to accurately measure water quality. This is in contrast to a relatively low-tech traditional water consumption meter that is relatively easier to install and maintain.

CHAPTER 4: APPLICATION OF IOT IN WASH MANAGEMENT – SOUTH AFRICAN CONTEXT

4.1 WASH VALUE CHAINS FOR SOUTH AFRICA

In order to contextualise the role that IoT solutions can play in the WASH domain, and to apply a baseline against which we can assess the examples of IOT solutions provided in Chapters 5 and 6, it is necessary to understand the value chains for water, sanitation and hygiene. A value chain in the WASH context represents a set of activities or processes that must be performed to deliver coherent WASH services. In general, the value chains for WASH services in South Africa are similar to the value chains for WASH services in the rest of Africa.

4.1.1 The Water Value Chain

As illustrated in Figure 4-1, the value chain for 'formal' water services is a nonstop sequential delivery process from source-to-tap and from tap-to-source [Department of Water Affairs, 2013, 2015]. It involves natural water resources, treatment works (processing), distribution infrastructure and effective operation to deliver potable (drinkable) water and safe sanitation. Rainfall runoff flows into rivers and is captured and stored in dams. Water from dams and other sources, such as groundwater, is purified and treated, and piped to reservoirs for distribution to customers (domestic, business and industrial users). Once the water is consumed, grey water (wastewater from washing, laundry etc.) and sewerage are collected and passed through a network of sewers to a treatment works. The wastewater is purified and treated, after which it is released back into rivers or dams, again becoming a water resource [Department of Water Affairs, 2013, 2015]. Figure4-2, derived to address the complete picture, is a schematic presentation of the sources of water and the diversity of water distribution in South Africa, and is also applicable to other African countries.

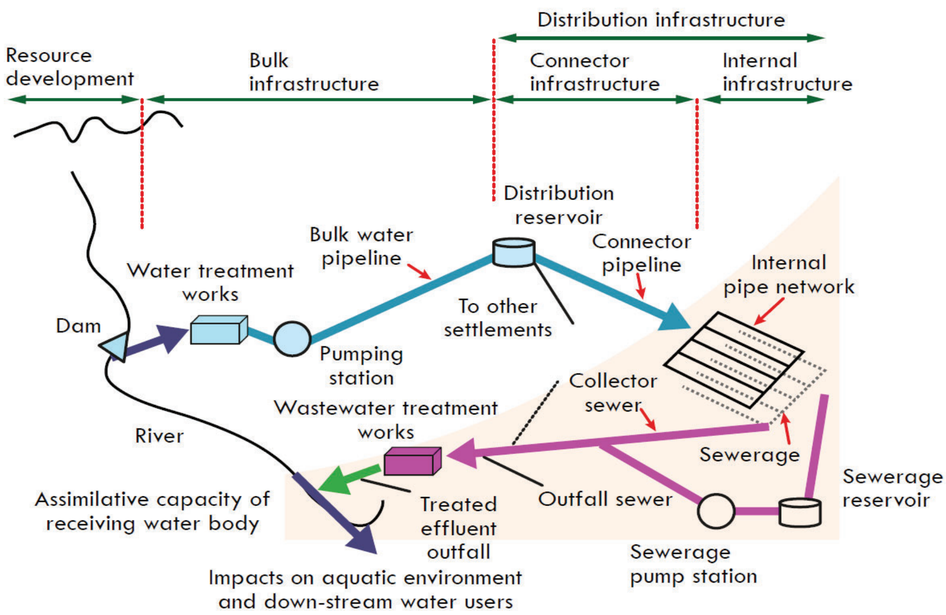


Figure 4-1: Water services delivery process from source-to-tap and tap-to-source in South Africa [Department of Water Affairs, 2015: p. 14]

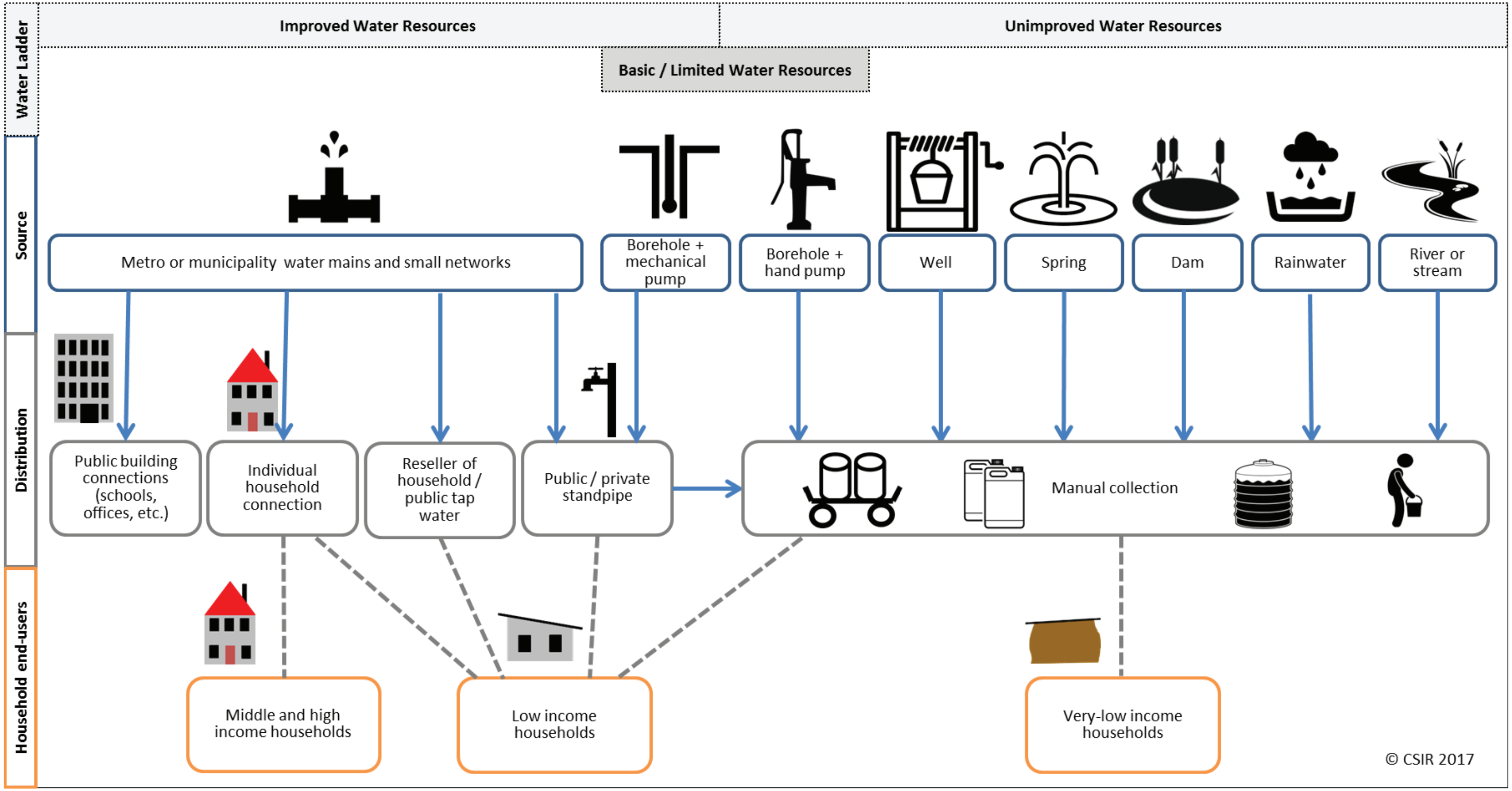


Figure 4-2: Value Chain for drinking water in South Africa

Figure4-1, however, represents only the 'formal' water sector perspective and does not provide the complete picture of the water sector is South Africa. It excludes the agriculture sector not dependent on the 'formal' water supply and the rural domestic water users. Agriculture is the largest user of water globally [Department for Business Innovation and Skills, 2013]. In 2015, agriculture in South Africa used 62% of the available water in the country [Department of Water Affairs, 2015]. Water use in agriculture, as a specific focus, is out of scope for this report. To cover the complete value chain for drinking water in South Africa, all the sources of water and water distribution should be addressed. Unlike cities in the United Kingdom, Europe, North America and other industrial nations in the north, where there is often a single source of water serving all residential and most industrial customers, in Africa (urban and rural) there can be a wide variety of water suppliers. Water can be obtained from household wells, neighbours' wells, springs, storing rainwater, water carriers, hand carters, carters using animal traction, standpipes, boreholes with manual pumps, or even individual connections to the 'formal' city or town water networks [Collignon & Vézina, 2000].

4.1.2 The Sanitation Value Chain

The sanitation value chain is fragmented, characterised by a wide range of stakeholders, businesses, from sole traders to multinationals, the majority responding to limited segments of the chain. Only a few companies/organisations have developed a business model that runs almost entirely across the value chain with the majority concentrating their core activities at either end of the value chain [Mason, Matoso, & Smith, 2015].

No specified value chain for sanitation for South Africa could be found in literature, but the general value chain for sanitation is also applicable to South Africa. The general sanitation value chain, as illustrated in Figure4-3, covers the following phases [Bill and Melinda Gates Foundation, 2010; Sahay, 2017]:

- Capture of sludge.
- Containment of sludge.
- Emptying of sludge.
- Transport of sludge.
- Collection and treatment of sludge.
- Safe reuse or disposal of treated sanitation waste.

Figure4-4 is a schematic representation, derived to present how the overall sanitation market works in South Africa, and which is also applicable to other African countries.

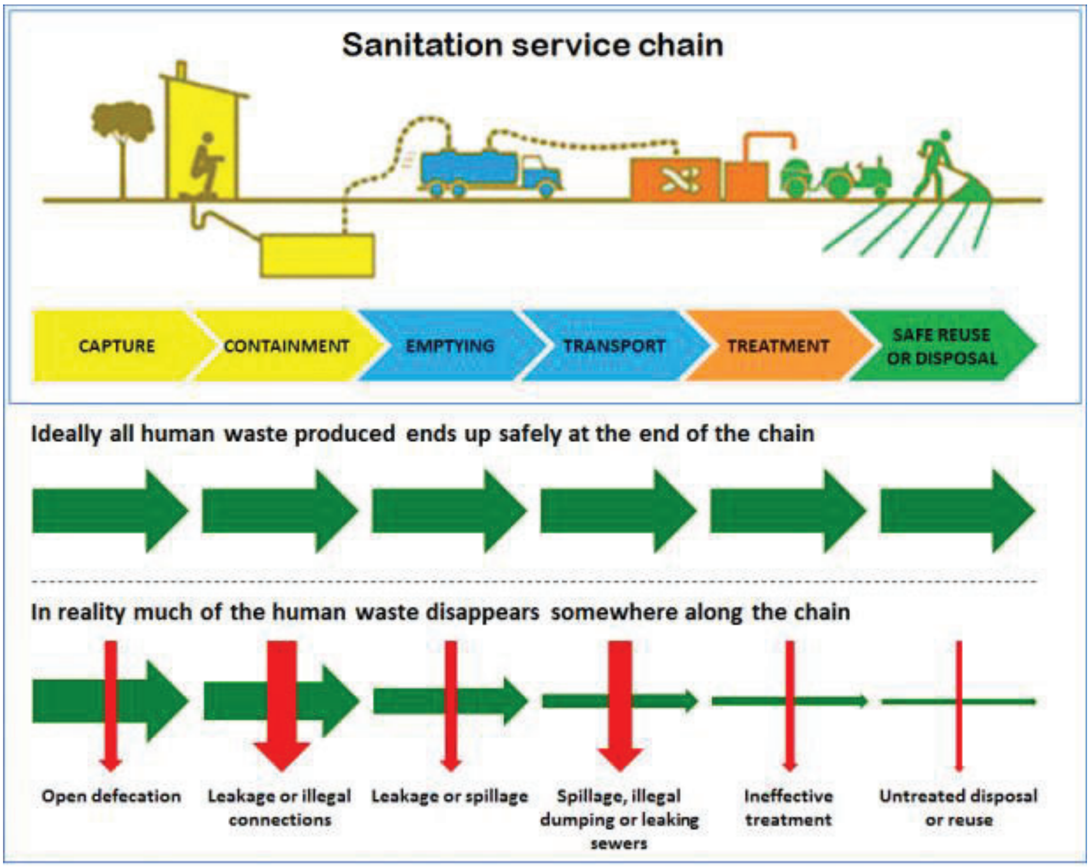


Figure 4-3: Sanitation value chain [Baetings, 2016]

Inhabitants adopt one of several basic solutions to the problem of disposing of human waste at the household level. The choice often depends on the physical conditions and on how much money they can spend on construction and periodic cleaning of the sanitation solution/facility. Solutions range from a simple pit or ditch, lined or unlined, with or without a platform slab, to a toilet with provision for flushing to a soak pit for the wastewater, or, at the high end of the market, a two stage lined septic tank and a piped sewerage system [Collignon & Vézina, 2000]. Figure4-5 gives view of the overall sanitation value chain based on manual treatment of sanitation waste where no sewer system or wet sanitation facilities is in place, and the reuse/disposal of treated waste.

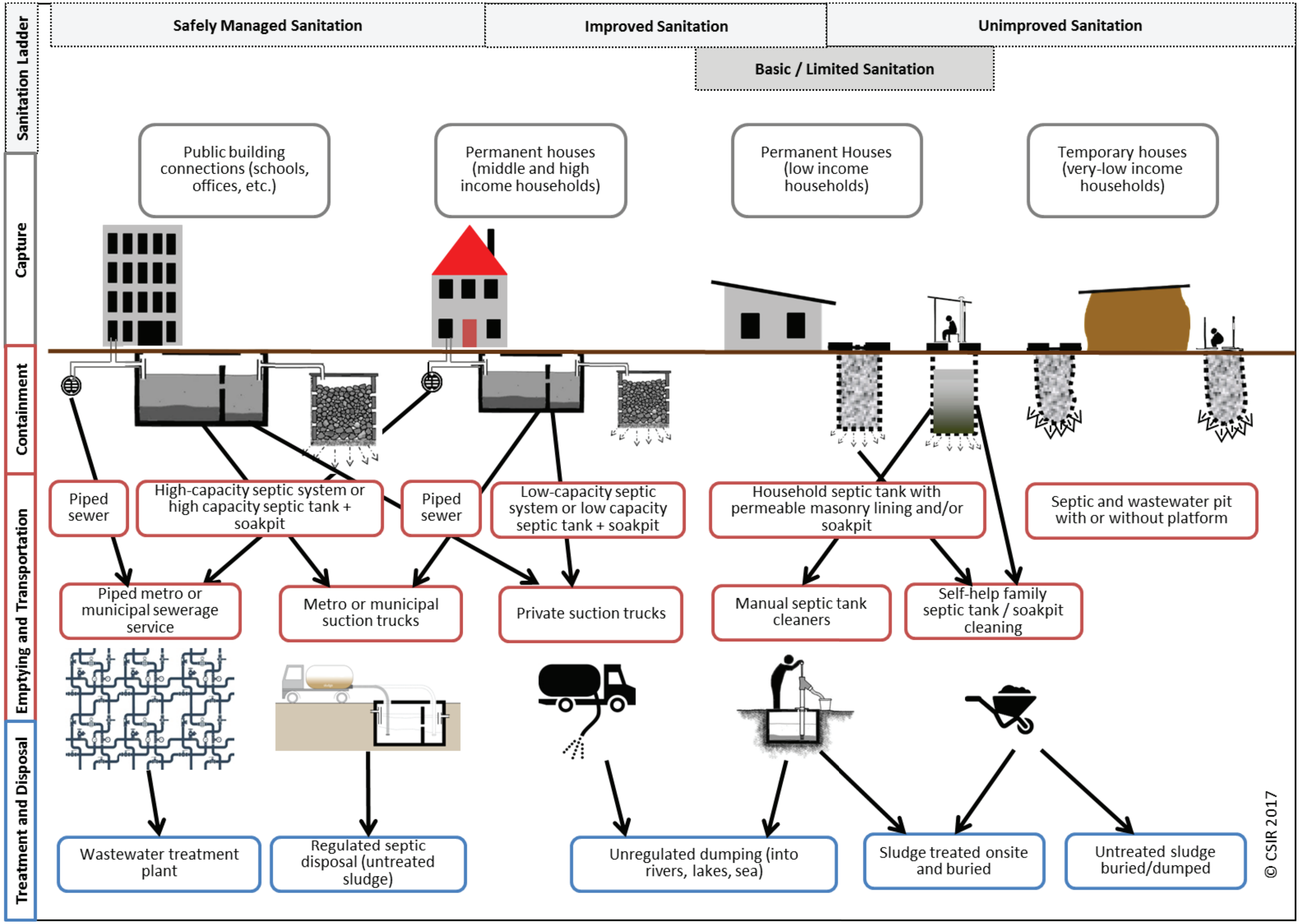


Figure 4-4: Value Chain for sanitation in South Africa

Figure 4-5: Sanitation value chain with manual treatment of sanitation waste (Image compiled from various SafiSan posters [Water Sector Trust Fund])

4.1.3 The Hygiene Value Chain

No value chain specifically for hygiene could be found in literature. Even though no specific value chain for hygiene exists, there are guidelines on when to wash hands and how to wash hands. In general hands should be washed [Water Sector Trust Fund; Wilkinson et al., 2012]:

- Before, during, and after preparing food.
- Before eating food.
- Before feeding children.
- Before and after caring for an infected or 'at risk' person.
- Before and after treating a cut or wound.
- After using the toilet.
- After changing diapers or cleaning up a child who has used the toilet.
- After blowing your nose, coughing, or sneezing.
- After handling soiled tissues (own and others).
- After touching an animal, animal feed, or animal waste.

- After handling pet food or pet treats.
- After touching contaminated surfaces, for example, garbage bins, cleaning cloths, food contaminated surfaces, etc.
- After contact with blood and other body fluids.
- After handling money (or using an ATM).
- After travelling.

CDC recommends the following process for washing hands when soap and water is available [Centers for Disease Control and Prevention, 2016]:

- *Wet*: Wet your hands with clean, running water (warm or cold), turn off the tap, and apply soap.
- *Lather*: Lather your hands by rubbing them together with the soap. Be sure to lather the backs of your hands, between your fingers, and under your nails.
- *Scrub*: Scrub your hands for at least 20 seconds. Need a timer? Hum the 'Happy Birthday' song from beginning to end twice.
- *Rinse*: Rinse your hands well under clean, running water.
- *Dry*: Dry your hands using a clean towel or air-dry them.

If soap and water are not available, CDC recommends the use an alcohol-based hand sanitizer that contains at least 60% alcohol [Centers for Disease Control and Prevention, 2016]. However, hand sanitizers are not as effective when hands are visibly dirty or greasy. Alcohol-based hand sanitizers can quickly reduce the number of germs on hands in some situations, but sanitizers do not eliminate all types of germs and might not remove harmful chemicals.

To use a hand sanitizer [Centers for Disease Control and Prevention, 2016]:

- Apply the product to the palm of one hand. Use the correct amount according to the label.
- Rub hands together.
- Rub the product over all surfaces of hands and fingers until hands are dry.

These processes have also been adopted in South Africa [Department of Health et al., 2016], with handwashing with soap the preferred method, since soap remains the best cleanser to use. If no soap is available or affordable, one can use ash, sand, or even mud as abrasive to help loosen dirt and then follow with rinsing under a stream of water [McKeever, 2014]. Research has also shown that that Moringa oleifera, a common plant in many tropical and subtropical countries, can be an effective handwashing product, in addition to the known antibacterial benefits against different pathogens, if used in the correct concentration. In a study in Mozambique that four grams of Moringa oleifera powder had the same effect as non-medicated soap when used for hand washing [Torondel, Opare, Brandberg, Cobb, & Cairncross, 2014].

As stated before, enabling products and technologies are some of the 'intentional external factors' that influence individuals' likelihood to perform a behaviour, regardless of their ability and motivation to take action [Devine, 2009]. In the case of handwashing, the tippy-tap is perhaps the best-known enabling technology. The tippy-tap is an African handwashing invention. The first 'official' tippy tap was built in the eighties by Dr Jim Watt in Zimbabwe using a gourd [Morgan, 2013]. The tippy tap is a hands free way to wash your hands that is especially appropriate for rural areas where there is no running water [tippytap.org]. A tippy-tap provides a controlled quantity of flowing water for washing hands and is made from locally available materials such as gourds or old plastic cooking oil bottles. It is a low-cost, do-it-yourself technology that has been widely promoted for over a decade, especially in Uganda and Madagascar [Biran, 2011], but also in South Africa [Department of Health, 2016b]

4.2 EXAMPLES OF IOT-RELATED PRODUCTS FOR SMART WATER MANAGEMENT

The sections below describe examples of the smart water management systems currently used in South Africa. It is not a comprehensive list of examples, as new devices enter the market on a continuous basis.

4.2.1 BRIDGIOT

Bridgiot [2017] provides two consumer products, 'Geasy', a smart geyser controller that is retrofitted to an existing geyser as well as smart water meters. Geasy primarily provides for energy consumption monitoring of a geyser with additional functionality related to remote device management. It also measures water consumption associated with the geyser (i.e. how much water was used during which period of the day). The smart water meter enables data acquisition, remote access, monitoring and control. Data is communicated to a cloud-based platform allowing for historic trend analysis. Furthermore, abnormal events (i.e. leaks) can be communicated to homeowners.

4.2.2 Aquatrip

AquaTrip [Aguatrip Australia Pty. Ltd., 2017], an Australian product also distributed in South Africa, is a permanently installed leak detection system with an integrated automatic shutoff valve. It constantly monitors the plumbing pipes, fittings and water using appliances where installed. If a leak is 'sensed', running tap or other plumbing failure is detected, it will shut off the water supply. The shutoff action is triggered by detecting 'abnormal' water use. Aquatrip also provides wetness sensing systems and water use monitors/meters.

4.3 USE OF IOT IN THE WASH SECTOR IN SOUTH AFRICA – STAKEHOLDER SURVEY INPUTS

A stakeholder survey was conducted to gain additional insights into the use of IoT in the WASH sector in South Africa. Online questionnaires were distributed to 47 stakeholders associated in some way (technical, management, policy, innovation) with the water, sanitation and/or hygiene domains. Three messages were undelivered, which means that 44 stakeholders were successfully contacted. Only seven responses to questionnaire were received, resulting in a response rate of 16%. The survey questions are provided an as Appendix to this report. The inputs received were collated an analysed. The following sections provide a summary of the most prominent trends and comments made.

4.3.1 Understanding of IoT

What the term 'WASH' entails: Although three respondents acknowledged the interrelatedness of water, sanitation and hygiene, the remainder only highlighted the water aspect and the management and use of water. Comments were made that sanitation and hygiene should not be seen as only a water issue, or covered entirely by addressing the availability and quality of water.

4.3.2 The IoT Concept

What the term 'IoT' entails: Although all the respondents mentioned the issue of collecting of data via sensors and communicating the collected data via some kind of communication network, and acting on data received, there were also comments about the hyped-up misuse of the term IoT as a 'panacea technology'. Reference was made to business and industry climbing on the IoT bandwagon, without realising what it really entails, what benefit can be gained from using IoT-related technology, or how IoT differs from other machine-to-machine (M2M) communication that have been used for years. One respondent referred to IoT in the context of the 4th Industrial Revolution, where IoT may also include the connection between people and intelligent machines.

4.3.3 Use of IoT in Service Delivery Examples

All existing examples mentioned related to WASH was limited to water and referred to smart metering and automated meter reading, i.e. to water resources belonging to the 'safely managed' water class. Other sectors not related to WASH that were mentioned included:

- Energy use: Smart/automated metering, pre-paid cash collection, loss management, tamper detection, energy reconciliation.
- Power generation: To remotely monitor power generation and to balance loads on the electrical grid.
- Waste management: A pilot in the Western Cape.
- Security and safety: CCTV in various municipalities.
- Collection of levies: e-Tolls for road users.
- Mining: Tracking vehicles and using the information in augmented technology for safety systems, for example collision avoidance.
- Petrochemical: Most petrochemical plants run a SCADA [Communication Technologies Inc., 2004] or other sensor and actuator monitoring and control system to fully automate critical processes to increase product quality and throughput, and decrease risk to staff in dangerous areas.
- Forestry: The use of the AFIS system [CSIR] for remote fire sensing, developed by the CSIR (considering satellites as 'things').
- Telecommunications, radio towers and broadcasting equipment: Remote monitoring of signal strength/travel for efficiency, leakage, interference and overall spectrum utilisation.

4.3.4 Barriers to the Deployment of IoT in WASH:

- IoT is cross-disciplinary: The silo-base public sector makes work spanning several departments difficult, if not impossible.
- Lack of IoT knowledge by the ordinary people, and lack of skilful technicians in the area.
- Technical: In WASH, sensors are for the most part underground or submersed, creating difficulty to supply power to field equipment a difficult problem to solve. Communication networks (to connect field equipment to back-end computer systems) suffer from the same complexities.

4.3.5 Opportunities for IoT in WASH in South Africa

- Opportunities for IoT in 'safely managed' water:
    - Water management across the entire water life cycle: To manage the demand, planning, storage, distribution, recovery, recycling and rationing of water. To indicate where water is needed, and to ensure the economy of water use in domestic, industrial and agricultural contexts.
    - Water resources, including water source security: monitoring of levels, monitoring of replenishment of resources (e.g. rainfall in catchment areas, river inflows, etc.), resource quality, pollution monitoring, and contamination alerts.
    - Water consumption: Monitoring, forecasting.
    - Water infrastructure management: tamper detection, leak detection, bulk water management and reconciliation, reservoir level monitoring, contamination prevention/detection.

  - Water processing and purification: plant monitoring, quality management, chemical use and monitoring.
  - Water generation: Condensation, desalination, etc.
  - Water use: Water usage monitoring (domestic, industrial) and control, water quality monitoring, smart metering for revenue collection and reducing revenue leakage,
- Opportunities for IoT in 'improved' water:
  - Smart pumps: To determine quality and volume of available/used water.
  - Rural water distribution: Water quality and equitable distribution.
- Opportunities for IoT in sanitation:
  - Should not see sanitation as only a water issue, but link it with the chemical sector and initiatives for natural filtering and rehabilitation;
  - Infrastructure monitoring/ management of 'improved' sanitation facilities: Flow metering, contamination alerts, contamination prevention, leak detection, sewerage plant outputs, ait quality, etc.
  - Waste collection.
- Opportunities for IoT in hygiene:
  - Hygiene is not considered a standalone system but linked to the availability of clean water and controlled sanitation facilities.
- Opportunities for IoT in WASH as an integrated/related concept:
  - Apart from the management of 'improved water' and sanitation infrastructure as independent initiatives, no IoT initiatives in the integrated WASH sector have been identified, but IoT is seen to have huge potential in WASH element and overall.

Overall, the inputs received from the stakeholders concurred with the findings of our literature review.

CHAPTER 5: BARRIERS AND CHALLENGES TO DEPLOYMENT OF IOT

5.1 INTRODUCTION

Even though the value proposition of IoT is becoming clearer, large scale IoT roll-outs are not common as yet. Most large scale roll-outs are associated with academic research (e.g. SmartSantander [Hernández-Muñoz & Muñoz, 2013]) or more domain specific (e.g. Industry 4.0). Numerous challenges still have to be resolved to ensure successful IoT roll-out. With the evolution and maturity of IoT, these challenges are becoming evident. Several viewpoints can be used to unpack aspects that impact on IoT roll-out and adoption. One viewpoint is one that is more generic and at a higher level (Section 5.2). A second viewpoint is of a technical nature (Section 5.3). In addition to the factors affecting IoT acceptance a perception exists that IoT solutions can be used regardless of context (Section 5.4). The sections below elaborate on these viewpoints

5.2 GENERIC IOT CHALLENGES

Viewing IoT from a broader departure point some of the challenges are:

- *Ensuring trust, security and privacy*: Data obtained through IoT can easily be used in ways damaging to people, organisations or environments. Any IoT roll-out must ensure trust, security and privacy as a fundamental requirement. Furthermore, compliance to ethics frameworks is critical as to further protect the citizen in an IoT environment.
- *Solving the interoperability challenge* (between device and middleware, middleware and application, as well as systems in a broader ecosystem): Examples of factors impacting interoperability challenges include:
    - Evolving (maturity and number) standards: Numerous standards are being developed (or have been published recently). This factor complicates the interoperability between IoT solutions. Currently no single standard dominates the market.
    - The explosion in the number of service (middleware) platforms: Middleware platforms implement different standards or use in-house defined technologies. This approach limits the interaction between systems from different vendors.
    - The number and heterogeneity of devices: With the rapid introduction of new devices, each with their own data formats, information models and communication protocols, middleware platforms need to be adapted to be able to incorporate data observations. This implies continuous evolving of platforms with associated increase in complexity leading to significantly higher costs.
- *Facilitating unique addressability through IPv6*: Each device and service needs to be addressable as to facilitate data communication. IPv4 has a limited number of IP numbers which limits addressability. IPv6 can address this limitation, but as yet IPv6’s uptake has not been as pervasive as was expected.
- *The development and maturity of business and governance models*: The value of IoT has become better understood. However, clear models to monetise IoT are still being developed. Similarly, governance models are being developed, which in turn impacts on aspects such as privacy.
- *Means to ensure citizen engagement and buy-in*: Rolling out an IoT solution without full participation, will often limit the impact of the roll-out. Providing services which are guided and informed by the citizen can increase the likelihood of success for the IoT installation.
- *Robustness of solution*s: IoT is still evolving, which in turn implies that not all technologies are robust to the point where the data, decisions and services are fully trusted. Technologies need to be verified and certified through the appropriate certification bodies to increase the likelihood of success.

- *Driving acceptance of data driven smart decisions*: Linked to robustness of the technology, society needs to adapt to a space where smart algorithms using the data collected will make complex decisions. Only through the passing of time and experiencing the value of IoT will society embrace the decisions made.

5.3 TECHNICAL CHALLENGES IMPACTING ON IOT ROLL-OUT

From a technical perspective, IoT challenges can be delineated along three axes, *data*, *communication* and *applications*.
Along the *data* axis the following aspects need to be considered:

- The scale of deployments.
- The heterogeneity and associated multitude of data sources.
- The mobility of data sources.
- The unstructured nature of the data.
- And often the need for near-real time delivery.

The *communication* axis relates to the connectivity and communication needs. The following aspects reflect the 'access' challenges:

- The cost of data.
- The required bandwidth.
- The infrastructure required for communication.

The *application* challenge relates to the following:

- The different needs that an application (or suite of applications) must solve.
- The different domains that need to be considered.
- The speed at which sense from the data is required.

In addition to the above described universal challenges, South Africa is also faced with challenges not typically present in developed countries. These include:

- Poor and expensive connectivity.
- Unregulated environments.
- Business models still evolving and mostly unsubstantiated.
- Expensive to import various technologies.
- Limited access to skilled technicians for support and maintenance.
- IoT is currently still a small local industry, which restricts the provisions of large scale, mass solutions.

5.4 DEVELOPING VERSUS DEVELOPED WORLD IOT SOLUTIONS

IoT is maturing rapidly in the developed world. Commercial solutions are becoming available. In addition, many research initiatives at scale have been pursued. There is also an abundance of skilled resources and technologies available. As alluded above, this is not the case in South Africa where the uptake is still in its early stages. This does create a challenge, as it is often believed that the required impact can be obtained by importing a 'canned' solution. Coetzee et al. [2015] have shown that canned solutions are not an optimal approach. The drivers quite often differ, thus impacting on the context in which a service needs to be developed (Table 5-1). As presented in the Table, different drivers for IoT exist in terms of South African and Europe. As a result, the outcome that is targeted in a specific domain would be different for different countries. This implies that significant refactoring of imported solutions is required, which might not be cost effective.

Table 5-1: IoT drivers in developed and developing worlds [Coetzee et al., 2015]

Domain	South Africa Driver	European Driver
Energy	Cost and reliability	Cost not a driver. 'Green' conscience is.
Water	Scarcity and shortage, Aging infrastructure, water pollutions; Technical/Non-technical losses (theft)	Abundance of clean water Unevenly distributed
Fire	Informal settlements use fossil fuel for cooking resulting in a high fire danger	Regulated settlements
Health	Uneven access to health services	Near-universal access to healthcare
Transport	69% road freight with significant impact on infrastructure Commuter transport unregulated and often unsafe	Improved logistics present 'Connected' commuter transport Seamless transportation networks
Waste	Industrial action impacts on collection Low efficiency in collection and recycling	Good awareness of when to pick up where and when Highly efficient
Pollution	Informal settlements use fossil fuel for heating and food preparation thus increasing pollution	EU has small number of informal settlements, but huge industries; Significant update of green power generation
Education	Uneven access to public versus private schools High dropout prevalent in public schools Need for developed skills at a higher rate	Average 17 years of education Aging SET population
Population	Younger population Very high unemployment	Aging population

5.5 CURRENT AND FUTURE IOT TRENDS

The understanding of IoT and its application is evolving rapidly. Many different views exist and differ significantly from stakeholder to stakeholder. Trends can be associated with hardware progress (e.g. devices becoming smaller with lower power needs), communication (e.g. the development of more effective communication protocols and network technologies), development in middleware platforms, as well as making better use of the data that is acquired. Trends are also noticeable in relation to where IoT are increasingly being used (e.g. in the healthcare domain through the use of wearables, and the expansion into driverless and autonomous vehicles). The importance of implementing a secure IoT solution has been highlighted and is one of the key topics that are being investigated. With IoT masses of data can be collected. The data provides deeper insight into a specific context, for instance in a factory or a smart home. However, it is in the deeper insight that the privacy of people can be intruded upon. Technology in itself cannot solve the right to privacy of an individual. Privacy rather lays in the trust a person places in an organization that is collecting data about his activities. It is for this purpose that organisations such as Google provide the ability to a user to request removal of indexed content. Removal however is still subject to Google's own policies. In South Africa the POPI Act caters for the protection of privacy [Republic of South Africa, 2013], but IoT's impact is unknown at this point in time. With IoT becoming more entrenched in our society, the impact and acceptance thereof is becoming more challenging. For instance, the European research community has recognized the importance of co-creation, not only to drive user acceptance, but also contribute to the IoT solution [SOCIOTAL, 2017].

One viewpoint in unpacking the trends is that of better use of the data, while another is from a pure technology perspective. Each of these viewpoints is briefly introduced below.

5.5.1 Data Driven Decision Making

McKinsey has stated that a significant challenge exist to effectively make use of the data being collected [Manyika et al., 2015]. However, a growing trend in applying artificial intelligence, big data and analytics for sense-making in IoT is starting to allow for better data utilization. Vermesan and Bacquet [2017] highlights how the integration of these machine learning techniques in every layer of the IoT stack (from an edge node for local decision making into a cloud platform for global decision making) is enabling new smarter homes, better optimised factories and in transport through autonomous vehicles.

Gartner has identified the top ten technology trends for 2017 [Panetta, 2016b]. These trends are presented in three categories, namely ‘intelligent’, ‘digital’ and ‘mesh’.

Within the *intelligent* category the following trends are presented [Panetta, 2016b]:

- *Artificial intelligence (AI) and advanced machine learning*: This category encompasses a number of technologies, including deep learning, neural networks and natural-language processing. These systems can learn, predict and adapt and operate autonomously. It is important to note that these algorithms are highly dependent on significant quantities of high quality data.
- *Intelligent applications (apps)*: Virtual personal assistants fall within this trend. Its main value proposition is making daily tasks easier and thus users more effective. The intelligence is created through the use of analytics and AI techniques.
- *Intelligent things*: Robots, drones and autonomous vehicles are seen as the broad use-cases, but will expand into other domains in future. IoT devices fall within this category where the intelligence will be created through the use of AI algorithms.

Within the *digital* category the following trends are identified [Panetta, 2016b]:

- *Virtual and augmented reality*: These two technologies impacts on the way people interact within an integrated cyber-physical system. Virtual reality allows for effective knowledge sharing (i.e. for training associated with a device), while augmented reality enables effective information sharing in a cyber-physical world. Using digital overlays of information as associated with a device contextual information becomes available.
- *Digital twin*: In an integrated cyber-physical system, physical entities (for instance the intelligent things described above) will be represented in the digital domain through a concept known as a ‘twin’. The twin contains all the relevant (meta) information related to the device. Furthermore the ‘twin’ contains knowledge of how the physical entity operates, the services it provides and the data it consumes and provides. Using this knowledge, the real-world can be simulated in the cyber space allowing for deeper insights into the interaction and effect of multiple smart things in an environment.
- *Blockchains and distributed ledgers*: Through the ledger technology distributed trust can be introduced into a large scale untrusted environment. The technology provides transparency as related to transactions between entities.

Within the *mesh* category the trends identified are [Panetta, 2016b]:

- *Conversational systems*: Refers to a model where a digital service ‘responds’ to a human’s desired outcome (an extension to previous capabilities where a computer only responded to a single instruction).
- *Mess apps and service architecture*: Propose a novel approach for the development of solutions. In this approach a number of different architectural components are combined (e.g. cloud, contains and micro-services, event driven processing and well-defined APIs) to deliver modular, dynamic and flexible solutions.

- *Digital technology platforms*: Refer to the building blocks required to create a digital business. Gartner states that several (if not all) of five systems will be required for digital business solutions. The five systems are information systems, customer experience, analytics and intelligence, the Internet of Things and business ecosystems. New solutions for IoT, AI and conversational solutions will increase in importance.
- *Adaptive security architecture*: Linked to the providing an end-to-end security solution. Security within IoT is critical, but in the same vein exceptionally challenging.

Analysing the trends described by Gartner, it is evident that IoT (and technologies enabling IoT) are seen as key areas going into the future. The ten trends presented above are all tightly integrated, and in one way or another refer to IoT (or enabling IoT) and to what is required to build a full featured IoT solution. The use of AI and analytics stand out as means to extract value from the data and allow for better decisions within a contextual environment.

5.5.2 **Technology Driven Trends**

Using the IoT reference architecture, trends of a pure technical nature can be identified.

5.5.2.1 *Hardware*

A key driver in IoT has been the proliferation of IoT devices with the ability to sense and act. Predictions from Cisco indicate that up to a billion devices will form the IoT in 2020 [Evans, 2011]. However, more recent estimates have been more conservative [Nordrum, 2016]. The entry barrier to using IoT is being lowered through a significant rise in the number of IoT devices and development boards entering the market. Examples include those presented by Postscapes [2017], where at the time of writing 167 development boards were available. It is believed that the trend of more Internet connected smart devices will continue thus creating more opportunities for IoT solutions over more domains.

5.5.2.2 *Communication*

The cost of data transport remains a significant barrier. In this context, the cost refers to two different dimensions. Firstly, cost is associated with the payment and procurement of data. Secondly, cost is associated with the power demands of actually sending data over the networks.

The concept of ‘edge’ computing (fog computing) is used as one way to mitigate the high financial cost of communication. In the edge, computing concept data is already processed (e.g. local analytics) before communicating the resulting processed data component to the backend. The processed data component will have a reduced communication overhead. However, edge processing also implies a higher cost in relation to the power consumption demands. Devices that are more powerful with higher power demand are required for the local processing.

To further mitigate the high cost of communication (both power and bandwidth) new protocols are being developed. One such protocol is the Constrained Application Protocol (CoAP) [Internet Engineering Task Force, 2014, 2016]. CoAP has a very low communication overhead as it uses User Datagram Protocol (UDP) as transport. This is in contrast to other popular protocols that use Transmission Control Protocol (TCP). TCP has significant overheads to ensure the guaranteed delivery of a packet. UDP on the other hand does not make guarantees in relation to the packet delivery. CoAP uses a low-overhead guarantee mechanism, thus avoiding the higher utilisation needs of TCP.

Work towards creating more effective communication technologies will continue with standards created and accepted.

5.5.2.3 *Middleware*

The choices in IoT middleware and platforms will increasingly become more difficult. New solutions are being created at regular intervals. The choice in such solutions has a direct impact on the technology stack (the implementation of the reference architecture depicted earlier) and the subsequent development, support and maintenance, and funding models [Hakala, 2017]. Gluhak and Vermesan [2016] have evaluated a large number of platforms which support the complexity in this space. A key conclusion in the report is that the IoT platform space is still highly fragmented. There is a need for the design and implementation of overarching platforms and integrated platforms that bring together solutions over multiple vendors, devices and algorithms. However, multinationals such as Microsoft, Amazon and IBM have entered the IoT middleware market. One can readily deduce that their activities will contribute to the convergence in the middleware space.

5.5.2.4 *Security*

The complexity in creating IoT solutions is significant as it spans numerous technology and application domains. This complexity is also manifested in securing IoT. In recent times numerous attacks on and using IoT has been published. This has raised the need for securing IoT as a fundamental and not as an after-thought. The challenges in securing IoT are also regarded as one of the limitations in the growth of IoT. In a report by McKinsey, gaps in the capabilities required for end-to-end solutions provided by system integrators is noticeable [Bauer, Burkacky, & Knochenhauer, 2017]. McKinsey identifies the system integrator as key to providing security as the end-to-end system allows for many potential attacks. This is in contrast to an individual component in the IoT stack that can be secured to some extent by the vendor. McKinsey highlights the lack of, or relative immaturity of standards within the IoT. Without the standards, interoperability becomes more challenging, which in turn impacts on the end-to-end security. The report also identifies the end user's unwillingness to pay for the required security components. Customers will accept a lower level of security at a lower cost and are not willing to spend more for better security features.

Awareness of the need to make IoT safer is increasing. Eastwood has identified four critical challenges in securing IoT [Eastwood, 2017]. In his analysis he states that with the increase in the number of devices, more opportunities appear. Furthermore, most customers and manufacturers do not update the devices which increase the associated risk. Data is the commodity. Corporations that create the devices now have good channels to access a user's data as acquired by the device. It becomes easy to misuse that data.

Microsoft suggests a complete and comprehensive security strategy. To this effect it publishes a set of best practices [Diogenes & Betts, 2017]. The best practices view IoT security from different viewpoints. These are from an infrastructure, hardware manufacturer, solution developer, solution deployer and solution operator viewpoint. Using these viewpoints, the security is layered thus providing increasingly more assurance.

5.5.2.5 *Data*

The data heterogeneity will continue to increase with the addition of more devices to IoT. However, these additional data streams will provide for better decision-making (machine learning and analytics) and thus increase the value of data for IoT.

CHAPTER 6: SUMMARY, FUTURE SCENARIOS AND CONCLUSIONS

6.1 IOT IN WASH SOCIETAL CHALLENGES

Although many technology challenges still exist for using IoT technologies in the WASH domain, most often the success or failure of a technology intervention is driven by the societal behaviour and acceptance. Section 2.3.7 highlighted the importance of combining technical and behavioural aspects to achieve continued success. The application of IoT in WASH, at a minimum, should contribute to driving interventions that can contribute to behavioural change. This emphasises the need of positioning IoT solutions to accomplish the 'determinants' stated in Table 2-15. For example, how to use IoT to drive 'handwashing with soap' behavioural change associated with Hygiene.

From our past experience we have observed the following:

- Community-driven solutions are required: With technologists as drivers for the development of solutions, the solutions are often driven by a technological problem. However, this technology problem is most often not the real point of pain that the community wants to have addressed.
- Long term sustainability is a significant challenge: The solution might have a high community uptake initially, but without a clear plan to ensure continuous operation the intervention very quickly will fall into disrepair. This in turn negatively impacts the community, with the result that future interventions are viewed with a certain amount of scepticism, even antagonism.
- Establishing mechanisms for transparency and trust for the solution and use of the information collected by the solution: The IoT solution uptake will be severely impacted if the community feels that their information is being used in a manner that is detrimental to them.
- Lack of knowledge of what IoT really is: IoT is often mistaken as a term to describe mobile applications or data collection using mobile devices. Although mobile technologies (GSM, GPRS, 3G, 4G, LTE, etc.) are still the most used underlying technologies in communication in IoT applications, not all mobile applications are IoT applications.
- Lack of technical IoT skills: Although machine-to-machine communication has been around for many years, technical skills to design and implement the more recent smaller sensor-based technologies, remote sensor networks and remote control and monitoring are still limited.

The IoT community in Europe has taken cognisance of the impact of society on the large-scale implementation of IoT projects. To enhance their understanding the European Union's Seventh Programme for research, technological development and demonstration (FP7) has funded a project "SOCIOTAL" aimed at creating a socially aware and citizen-centric Internet of Things [SOCIOTAL, 2017]. This project has taken an approach to equip communities with trusted tools to increase user confidence in the IoT environment. It is believed that through this approach, the transition to a 'smart' environment will be expedited if it is linked to a participatory open ecosystem, as it would lower the barriers of entry for society.

6.2 IOT IN WASH TECHNOLOGY CHALLENGES

To apply IoT in WASH successfully, a number of technology challenges need to be resolved. Using Figure 3-2 as basis, innovative solutions need to be put in place for IoT to create impact. The following expands on the challenges as described in Section 6.5, but rephrasing those in the context of WASH and how to mitigate them.

6.2.1 Devices Tier

- Support and maintenance of devices in the field are critical to the successful application of WASH. An innovative business solution in which the local community is actively participating is required. An incentive-based scheme where the local community can either report a device failure, or apply basic maintenance is one possible way to achieve this.
- Powering devices in the field is required. Access to the main power grid is often not possible. In situations where power is not available, the choice of devices and their power source become important. The devices need have low power consumption requirements, preferably running off batteries recharged through solar technology. Energy harvesting from the environment is one way of addressing the power need.
- The cost of devices can be a limiting factor, especially for broad- and scaled roll-out of solutions. Care should be taken in selecting specific field devices, with replacements for devices readily available. In addition, replacement of such devices should be fast, of limited technical complexity, and thus allowing for the local community to provide support and maintenance.
- Devices need to be robust and hardened to ensure continued operation in harsh environments. However, there is a trade-off in relation to cost as industrializing devices have a higher cost.

6.2.2 Edge Tier

- Similar to the devices tier, power remains a critical factor for gateways in the edge tier. These gateways most often are not linked to the main power grid, with the result that the gateway devices need to have low power requirements from the onset. A critical element in the power consumption is the type of radio, network and transport protocols used to communicate data observations from the edge. Low-power, low-bandwidth approaches such as LoRa [Semtech, 2017] are popular, given that the bandwidth is limited. Higher bandwidth (such as WiFi) has higher power needs.
- The choice of transport protocol for data communication is important. In a situation where only telemetry data is required, a protocol such as MQTT [MQTT.ORG, 2014] would be a good choice. However, in a situation where bi-directional communication is required (e.g. to actuate a valve on a pipeline), a protocol such CoAP [Bormann, 2016] would be more appropriate.
- The choice of *what data* to communicate depends on the planned use-cases. It is not always practical to communicate all possible observations, all the time, due to the demand on battery as well as costs of communication.
- ‘Edge computing’ has become more popular. In this approach data is already processed and aggregated on the gateway device. Only the result from the local processing is then communicated to the backend. This results in lower data communication needs, as well as a reduction in the processing needs on the hosted backend middleware service.

6.2.3 Middleware tier

- Ensuring *interoperability* between middleware instances, a host of protocols and a multitude of standards is a significant challenge. Choices vary from bespoke open-source implementations (Kura [Eclipse, 2017b], Kapua [Eclipse, 2017a]), implementations of open standards (e.g. oneM2M [oneM2M Partners, 2017]) or commercial offerings (Microsoft IoT Azure [Microsoft, 2017], IBM IoT Watson [IBM, 2017]). In the WASH sector, platforms such as Akvoflow [Akvo, 2017] has been utilised (Akvoflow provides functionality for field workers with smart phones to collect information and communicate that information to the backend). Regardless of the platform, the cost is significant. With the open-source approach, support and maintenance must be done by the community, which is not always readily available and may have a cost implication. The implementations of open standards are increasingly complex (e.g. oneM2M), thus implying a very high barrier before it can be used. The commercial offerings have a cost associated with each data observation submitted to the platform. For a scaled environment, this can become prohibitively expensive.

- *Contextual information* related to the data observations is required. The meta-information of a data observation must be known, i.e. this is the flow-rate in a pipe, and it is measured in this specific unit. Similarly, this is the temperature of a device and it is measured in degrees Celsius (rather than Fahrenheit). The contextual information stretches further as the type of device must be known, what the performance parameters are, where it is situated and who is allowed to have access to that device. Middleware platforms often implement this in a component known as a *digital twin* [i-SCOOP, 2016].
- Data varies significantly in its characteristics. The veracity (can the data be trusted), variety (different forms of data), velocity (streaming data analysis) and volume (scale of data) need to be catered for in the choice of middleware as well as communication and transport protocols [IBM Big Data & Analytics Hub, 2013, 2016].
- The tooling associated with a middleware solution is a significant factor. Libraries should ease the development of solutions. As an example both CoAP [Bormann, 2016] and MQTT [MQTT.ORG, 2014] provide good supporting libraries.
- A *future proof* approach must be followed as new offerings are coming to the market at a rapid rate in addition to those already in the market [Gluhak & Vermesan, 2016].

6.2.4 **Cross-cutting**

- Knowing the status of installations (both in-situ as well as cloud-based middleware and applications) is critical. Technicians need to be informed in a timely manner if a problem has occurred in a specific component. This also implies that diagnostic information for the scaled installation needs to be available. One technology that has been used successfully is Zabbix [Zabbix LLC, 2017]. Zabbix provides for data collection from sensors and devices which can easily be visualised in dashboards.
- Providing the means for remote maintenance (both at the edge as well as device tiers) is required. To avoid costly updates (i.e. a remote area needs to be visited for the updates), functionality to provide over the air updates of firmware and edge/device applications are required.
- Security is the key and critical of any IoT solution. It refers to being to trust the devices and sensors, the data observations, the users able to access the data and the applications hosted on the middleware

6.3 FUTURE SCENARIOS

Section 4 and 5 presented insights as acquired from numerous reports and publications. From the studies, good views of current IoT (ICT) activities related to water (smart water management) as well as IoT WASH solutions were obtained. As commented the solutions are patchy, i.e. often only focussing on one aspect within WASH and therefore not utilising the full value cycle of IoT. This section presents a broader view of what IoT can bring to the WASH sector and what should be in place to increase the probability of success. IoT as ecosystem enables a complete value chain, from data acquisition, processing and finally actuation with the community in the loop at all time. IoT is multidisciplinary, spanning competences ranging from device and sensor manufacturing, up to analytics and visualization techniques. The true value of IoT is only manifested when intelligent decisions are being made with the acquired data, resulting in appropriate actions. Furthermore, IoT is completely dependent on addressing the ‘real’ challenge which only becomes possible if the community is part of the IoT lifecycle.

In driving towards a scaled IoT deployment the following aspects need to be in place as to increase the chances for success:

- Policies for community privacy and security.
- Partnerships linked to research and local community as well as vendors. The partnerships should also include the various governing structures (e.g. the local water board).

- Buy-in from the community.
- An established ecosystem that spans technology and community.

Section 5.5 highlighted the increased popularity of big-data and analytics in IoT. An IoT enabled WASH environment that is operating at scale provides access to large quantities of data observations. For a broad IoT deployment these data observations should ideally be from multiple sensor types (e.g. hand pump utilisation, water quality and flow in the pipe, sanitation pit level, etc.). In such a scaled IoT deployment, the following benefits can be obtained:

- IoT provides better data. The data is associated with the context being observed (e.g. water quality). With better data 'evidence-based decisions' become possible. IoT data can be supplemented through community contributions or surveys.
- IoT enables better working infrastructure. Access to the status of the deployment (i.e. all devices are operational) becomes possible and thus empowers maintenance crew to effectively and rapidly service the infrastructure. With increased access to the operational parameters of the devices, predictive maintenance becomes a reality.
- From IoT the context of an environment will increasingly become better understood. This creates an opportunity for the introduction of key performance indicators (KPIs) that will provide insights into the operational efficiencies in environments.
- Community involvement throughout the lifecycle of the deployment is critical. Having the community involved ensures that the 'real' problem is solved and not the one that appears to be the most attractive (e.g. flashy). With community involvement localised business models can be realized. For example, a local community member can be informed of required maintenance. This local community member is on the ground, which allows for faster turnaround times.

The description above describes the value of IoT in a fairly broad sense. Using the value chains depicted in Section 4.1 as guide, more detailed application of IoT and what becomes possible is described below.

6.3.1 Water supply and safety

- Water *quality* can be measured continuously through in-situ sensors installed permanently or through 'use-once and discard' type of sensors. This allows for early alerting where the water quality has dropped outside of the required parameters. This approach works for piped water, boreholes, tube and dug wells, springs, and packaged or delivered water. Water treatment plants can be measured before and after the treatment process. Data related to taste, colour and odour can be obtained.
- Indicators related to water *distribution* can be obtained near real-time. Pressure within pipes can be measured in different locations. Pressure differences can indicate a leak, while a high-pressure point can provide alerts related to possible failures. Smart valves can be used in the distribution system. The smart valves can control the flow of water (e.g. shut off in case of failure, or if the pressure appears to be too high).
- Water *availability* can be confirmed through sensors that indicate the water level (for instance in a dam or borehole). Trends can be extracted which in turn can guide the community as well as providers as to the future availability of water.
- *Power* availability can be measured. Pumps in distribution networks are dependent on power. Awareness of the power status in a community can empower providers to institute emergency processes to ensure continued availability.

6.3.2 Sanitation

Excreta management can be enhanced through IoT. Sensors linked to the appropriate back-end systems can provide insights as to when a pit or sanitation tank has reached capacity and needs to be emptied. General waste management (e.g. solid waste) can be also be improved with the appropriate sensors. The value can be enhanced further by optimising the routing of waste trucks and the dispatch of the appropriate truck.

6.3.3 Hygiene

Handwashing has been highlighted as one of the most important criteria for both hygiene and sanitation. Using IoT, a number of different approaches can be followed to raise awareness of when hands should be washed. One approach is sensing when a toilet has been flushed, and if the basin has been used directly after the toilet flushing. A general reminder can be communicated to the occupant through smart visual aids when leaving the rest room. Trends from handwashing can be built and used as indicators of when and if additional awareness campaigns should be executed.

6.4 CONCLUSION

The aim of the study was to obtain insights into the value and potential use of IoT in the provision and management of WASH services in the South African context. It is believed that the knowledge presented will allow for future effective application of IoT to create value related to WASH.

The study found that limited use is currently made of IoT in the WASH domain in South Africa (and Africa). Currently the use of IoT-related technology in South Africa is in the smart water (safely managed) management domain, which is mostly limited to measuring the amount of *improved water* use and payment for it, primarily in metropolitan areas. No use is made of IoT to improve the livelihood and health of the majority of the South African population, and especially those depending on basic, limited or unimproved water resources, basic, limited or unimproved sanitation facilities, or basic or limited handwashing facilities. This finding was supported by both the literature review and the inputs received from the stakeholder's responses to the survey.

Viewing WASH holistically the following observations can be made:

- WASH is well established as a sector internationally. In South Africa WASH is not seen as a singular sector, but rather as separate fields.
  - This implies that internationally criteria related to WASH is well defined, with sufficient data and information available.
  - At a local level WASH is served through multiple national government departments which also imply that integrated data is not readily available.

The following observations related to IoT can be made:

- No singular definition of IoT has become mainstream. This implies that IoT is still an evolving concept.
- Many different vendors and technologies are active in the International IoT space (quite often in the consumer domain, however the Industrial Internet of Things have become more prominent recently). With so many role players active in the field the making choices in relation to vendors, technologies, standards, etc. are difficult and will impact on any solution.
- At a national level IoT still has a small footprint. These IoT solution providers most often have a focus on resource management (in this case smart energy is quite popular).
- Nationally the understanding of IoT is still evolving and will take time to significantly penetrate the market.
- Internationally, testbeds have been used successfully to bridge the gap between the lab and the real world. Within the South African context testbeds aligned to WASH are an absolute necessity as to allow for technologies to be developed, adapted and used in our local context.

In relation to IoT (and subsequently IoT and WASH) the following comments can be made:

- IoT solutions must be community driven. This is also very important in WASH as without the required community buy-in it is unlikely that any solution will have the required support and long levity.
- Communities of practise in relation to application of IoT (in general, but more specifically in WASH) are not well established. Knowledge is constrained to silos, mostly aligned with a specific initiative or commercial products. Access to the knowledge is typically through academic peer review papers, or vendor web sites.
- Sustainability in relation to IoT solutions are challenging. More work is required to identify appropriate business models.
- Most often trials in Africa were supported by international donor funding programs. As a result, these trials were completed without a clear understanding of how the trials can be transformed into fully fledged and long running operational interventions.
- Transparency and trust is critical. Communities will not engage without clear commitments that the insights, data and other confidential information will not be used in any inappropriate manner.
- Local technical skills (associated with research and development as well as support and maintenance) are a challenge, and most likely will remain this way into the foreseeable future.
- Technologies will increasingly become “commercial-off-the-shelf” which will lower the entry barrier in relation to rolling out solutions.
- Devices need to be hardened to safely and reliably operate in very harsh conditions. This however has a cost implication as industrialized device will be more expensive.
- The challenge in relation to where the ultimate responsibility lies need to be resolved before any field deployment. A community might trust the water quality measurement implicitly but can be put at risk if a sensor fails. The community will be at risk without the knowledge that the data is incorrect. The question then would be who takes responsibility if a person is negatively affected.

Apart from the current focus on ‘urban’ applications of IoT in mainly the water sector, which is also necessary, there are therefore huge opportunities to investigate the use and benefits of IoT in WASH as an integrated and interlinked domain. Vast opportunities also exist for research to determine how IoT technologies can be used to improve the lives and health of the large proportion of the South African population depended on WASH services that cannot be classified as safely managed, improved or advanced, and to develop suitable technologies to fit such environments. As the technology is still evolving, it is recommended that testbeds are used as vehicle to expand on the national IoT capability and its application in WASH. In this way technology can be advanced, as well as better understanding of appropriate business and support models can be gained.

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APPENDIX A: STAKEHOLDER SURVEY QUESTIONAIRE

WRC/CSIR WASH Questionnaire

The Water Research Commission (WRC) has contracted the Council for Scientific and Industrial Research (CSIR) to do a review of the use of Internet of Things (IoT) technologies and applications in the water, sanitation and hygiene (WASH) domain. The purpose of this questionnaire is to obtain stakeholder views as input to the review.

How to fill in the questionnaire

We would value your inputs to the questions related to the use of IoT in the WASH domain. Please provide answers to the questions you feel capable or willing to answer or wish to provide a response to – it is not compulsory to provide an answer to all of the questions.

Questions

1. WASH is an abbreviation for water, sanitation and hygiene as interdependent domains. Very briefly state your understanding or viewpoint on the WASH concept. The description can include your definition of WASH or what you understand the term WASH to mean, or the specific aspect of WASH you specialise in or are interested in. The aim of this question is to provide a context in which to interpret the answers to the questions that follow.
2. Similarly, what do you understand the term 'Internet of Things' (IoT) to mean.
3. Do you have any specific view on the use of IoT in public sector service delivery, in general, and the WASH sector, in particular?
4. Do you know of any other service delivery sector(s) in South Africa that have made successful use of IoT?
5. What do you see as the possible barriers to the deployment of IoT in the WASH sector?
6. How would you describe a successful IoT deployment in the public sector?
7. Is there an area in the water sector service delivery that you think can benefit from the use of IoT?
8. Is there an area in the sanitation sector service delivery that you think can benefit from the use of IoT?
9. Is there an area in the hygiene sector service delivery that you think can benefit from the use of IoT?
10. Do you know of any existing or planned South African examples of the use of IoT in the WASH sector as a whole, or the water, sanitation and hygiene sub-sectors as standalones?

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