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Opportunities for the Internet of Things in the Water, Sanitation and Hygiene Domain

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Abstract. This paper analyses the water, sanitation and hygiene (WASH) context in South Africa and presents views regarding the possible use of the Internet of Things (IoT) for WASH in South Africa. The views were informed by an analysis of literature related to the WASH domain nationally and internationally. Example case studies of the use of IoT in the WASH sector in developing countries, and where possible Africa, provided further background. As a triangulation exercise, a survey amongst various stakeholders in the WASH domain was conducted. To contextualise the WASH sector in South Africa, value chains were derived. To identity the opportunities for IoT, the findings of the study were combined with insights acquired on the IoT domain in general, both from literature and our experience and learnings.

Keywords: WASH · Internet of Things · Water · Sanitation · Hygiene · Value chains

1 Introduction

The human rights to water, sanitation and hygiene, collectively known as WASH, are 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 [1], 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 [1–5]. Reporting on progress with the United Nations (UN) Millennium Development Goals, UNICEF states that [6]:

- More than 660 million people in 2015 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 was dependent on surface water, of which 102 million lived in Sub-Saharan Africa.
- Adequate sanitation facilities, for human excreta disposal in, or close to, peoples' habitation, were not available to 2.4 billion people in 2015, 695 million of which lived in Sub-Saharan Africa.

In South Africa, and many other developing countries, a large number of people still do not have an acceptable toilet and cannot easily access safe water to drink or wash their hands. This leaves significant proportions of young children and vulnerable individuals

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to die of preventable WASH related diseases such as diarrhoea, intestinal nematode infections, lymphatic filariasis, trachoma, schistosomiasis and malaria [7]. This could also contribute to malnutrition and poor school attendance, which could result in cognitive impairment and reduced learning outcomes [8, 9]. It is argued that 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. Access to adequate WASH services is therefore an important mechanism to address risks associated with the burden of disease of any country.

The use of information and communications technologies (ICTs) has been posited as one way to address 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. In the context of WASH innovative IoT work, including technology development and applications, is being done in relation to WASH services in both the developed and developing world. However, it is unknown to what extent (and if at all) IoT approaches to providing WASH services have been pursued in South Africa.

Following a study conducted for the Water Research Commission of South Africa (WRC) [10], this paper analyses the WASH context in South Africa and presents views regarding the possible use of IoT for WASH services in South Africa. A literature review combined with inputs from a survey was used to collect data for the study.

Section 2 provides background to the WASH domain and IoT in general. Section 3 provides an overview of the findings of our study on the use of IoT in WASH in South Africa. Section 4 contextualises the WASH sector in South Africa using value chains. Section 5 identities benefits and future scenarios for the use of IoT in the WASH sector. Section 6 concludes the paper.

2 Background

2.1 What Is WASH

WASH is the collective term for the associated concepts of safe drinking water, safe sanitation and hygiene [2]. According to the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) [11]:

- *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. [2]. This paper addresses the WASH concept as defined by the JMP [11], but limiting the hygiene aspect to handwashing.

2.2 Global WASH Context

The UN 2030 Agenda for Sustainable Development [12], comprising 17 Sustainable Development Goals (SDGs) and 169 targets addressing social, economic and environmental aspects of development, seeks to end poverty, protect the planet and ensure prosperity for all. Concerning WASH services, Goals 6, 1.4, 3.9 and 4a [12, 13] apply. In the context of this paper SDGs 6.1 and 6.2 are specifically relevant:

- SDG 6.1: By 2030, achieve universal and equitable access to safe and affordable drinking water for all.
- SDG 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.

The UN also identified a number of cross-cutting criteria for good practices in the WASH sector [3]: non-discrimination, participation, accountability, impact and sustainability.

JMP [11] is the custodian of global data on WASH and has derived a normative interpretation for SDG 6.1 and 6.2. JMP also compiled associated service ladders to benchmark and compare service levels across countries and to facilitate enhanced global monitoring of WASH as specified in the SDGs [13]. The JMP ladder for household drinking water services consists of five rungs and also classifies the water resources into four classes [11, 13], as presented in Table 1. Drinking water ladders also exist for schools [13, 14] and healthcare facilities [13]. The JMP service ladder for sanitation for households is presented in Table 2. A service ladder for sanitation in schools also exist [13–15].

The full benefits of improvements in access to sanitation and drinking water cannot be realised without good hygiene. Although there is a distinction between sanitation and hygiene, the two topics are often covered together in literature. Handwashing with soap is considered the main focus for hygiene as it 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 [16]. JMP's service ladder for handwashing in households is presented Table 3. Handwashing facilities can consist of a sink with tap water, or other devices that contain, transport or regulate the flow of water [13], for example buckets with taps, tippy-taps [17] and portable basins. JMP also has a handwashing ladder for schools [14].

Table 1. Water service levels and resources [11, 13, 18–21]

Service level	Service criteria	Resource class	Resource	Resource example
Safely managed service	Accessible: on premises Available: when needed Quality: free from faecal and chemical contamination Affordable	Improved	Sources, which by nature of their design and construction have the potential to deliver safe water	Piped water, boreholes or tube wells, protected dug wells or springs, packaged water
Basic service	Improved source does not meet any one of above normative criteria A round trip to collect water ≤ 30 min, including queuing time	Improved		
Limited service	Round trip for water collection >30 min, including queueing time	Improved		
Unimproved		Unimproved	Collected from source	Unprotected dug wells or springs
No service		Surface water	Collected directly from an unprotected resource	Surface water, e.g. lake, river, stream, pond, canals, irrigation ditches

Table 2. JMP service ladder for sanitation in households [13, 15]

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 3. JMP service ladder for handwashing in households [14, 15]

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

2.3 What Is IoT

Multiple definitions for the Internet of Things have been proposed in the past [22]. 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" [10: p. 50]. Figure 1 presents the generic IoT process chain. Observations are acquired via a variety of sensors and 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.

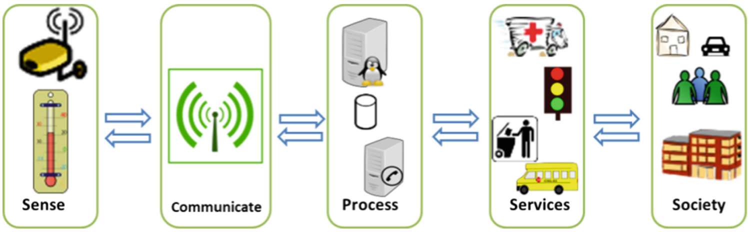

Fig. 1. IoT process chain [10]

IoT is maturing rapidly in the developed world. Many research initiatives at scale have been pursued and commercial solutions are becoming available. There is also an abundance of skilled resources and technologies available. This is not the case in South Africa and the rest of 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. [23] 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.

3 Study to Determine the Status of IoT Use in WASH

The study flowed from a project conducted for the Water Research Commission of South Africa [10]. A literature review combined with inputs from a survey was used to analyse the WASH context in South Africa and present views regarding the possible use of IoT for WASH services in South Africa.

The goal of the literature review was to determine the normative standards applicable to the WASH sector, the WASH context in South Africa and the use, or possible use, of IoT in the WASH sector in South Africa. The review therefore focused on the criteria for WASH related services as set out by the United Nations General Assembly [12] (see Sect. 2.2), WASH value chains and role players, existing IoT technologies, trends and implementations, and existing case studies in IoT or similar domains. In the absence of case studies specific to South Africa, examples from other African countries were included.

The survey amongst stakeholders active in the technical, research, industry and policy domain related to WASH services, aimed to determine the current perception of the WASH sector and the use of IoT in service delivery in the WASH. The survey consisted of open-ended questions addressing the following topics: the WASH and IoT concepts, use of IoT in public sector service delivery (including WASH), what a successful IoT deployment in the public sector means, barriers to the deployment of IoT in the WASH sector, areas in the water/sanitation/hygiene sector service delivery that can benefit from the use of IoT, and any existing or planned South African examples of the use of IoT in the WASH sector or sub-sectors. Online questionnaires were distributed to 47 stakeholders. Only seven responses to the questionnaire were received, resulting in a response rate of 16%. The inputs received were collated, analysed and integrated with those from the literature review.

3.1 WASH Context in South Africa

The literature review found that there is no integrated WASH sector or initiatives in South Africa. Responsibility for WASH services on government level are spread over various national and provincial departments, with overlapping mandates. Internationally, several large bodies, companies and NGOs are active in the WASH sector, some with a focus on the use of ICT. Some of the most prominent of these are the European Commission (e.g. ICT4Water Cluster [24]) and the ITU (e.g. Biggs et al. [25]). Multinationals (e.g. Google [26]), academia (for example, Oxford University [27]) and several NGOs (for example, the Toilet Board Coalition [28]) have a footprint through research, innovation and roll-out initiatives.

From the responses to the survey it appears as if the WASH concept is still not well established. 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. Concern was expressed that sanitation and hygiene should not be only a water issue or covered entirely by addressing the availability and quality of water.

3.2 IoT in WASH in South Africa

The literature review found that although IoT are increasingly applied to numerous domains in the context of WASH, overall it is mostly limited to billing purposes and smart water resources management (using smart meters) in the improved water domain in urban areas [24, 29–31]. This also applies to South Africa [32–34] and the rest of Africa [35–37]. There are, however, some examples of other uses of IoT for in-situ monitoring and information collection for rural and developing country contexts. Examples include sensors used by Charity: Water [38] to capture the location, determine the state of wells and if the wells need to be fixed, and accelerometers used in water lever hand pumps to measure utilisation and status of the pumps at specific water points [39]. Other examples are the Akvo [40] applications in Liberia and the Mwater application in Tanzania to measure and communicate the water quality of a water point [36], both which can be used across the water value chain. An example in the basic/limited sanitation domain include the use of sensors to indicate the presence of 'solid waste' in waterless toilets in informal settlements in Kenya [28, 41].

Examples of IoT use in the WASH domain obtained from the stakeholder survey were limited to water and referred to smart metering and automated meter reading *(i.e. safely managed* water). The cross-disciplinary nature of the WASH domain, alongside a lack of IoT knowledge by ordinary people and technical IoT expertise, were listed as barriers to the deployment of IoT in the WASH domain. The issue of appropriate sensors for the harsh environment of the WASH domain, which is mostly submerged or underground and exposed to pollution, was highlighted. Opportunities identified for IoT in the *improved* water sector included measuring the quality and volume of available/used water for smart (hand) pumps, as well as water quality and equitable distribution of rural water supplies. For the sanitation section, the controlled use of chemicals and natural filtering and rehabilitation, was noted as alternative to water.

These examples by no means address the full potential of IoT in the WASH sector in (South) Africa. Most of the available technologies and publications are associated with water resource management, and in most of the cases billing. Sanitation and hygiene have not featured prominently in literature or the stakeholder survey. 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 an able robust sensor that can be installed in the field to accurately measure water quality. This contrasts with a relatively low-tech traditional water consumption meter that is relatively easier to install and maintain.

Overall, the inputs received from the stakeholders concurred with the findings of our literature review. However, a key outcome from both was that it is necessary to understand the context in which WASH services are supplied to determine the role that IoT can play in improving such services.

4 Value Chains for WASH

As a first step we therefore had to map the WASH context in South Africa using the UN and JMP criteria as guidelines. The concept of physical service value chains is one way to depict such context and is used as an example in this paper to depict the WASH context in South Africa. A value chain in the WASH context represents a set of activities or processes that must be performed to deliver coherent WASH services. From the literature review it was found that, 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. The value chains for South Africa would therefore also be applicable to the rest of Africa and most of the developing world beyond Africa.

4.1 Water Value Chain

Several value chains for 'formal' or improved water and sanitation services in South Africa were found during our literature review. In general 'formal' water services is a nonstop sequential delivery process from source-to-tap and from tap-to-source [42, 43]. 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 [42, 43]. This formal water and sanitation sector perspective does, however, not provide the complete picture of the water and sanitation sector is South Africa and Africa. As a start, it excludes the 'non-formal' water sources and sanitation services, as it applies to most of the rural domestic inhabitants. It also excludes the agriculture sector not dependent on the 'formal' water supply. Agriculture is the largest user of water globally [30]. In 2015, agriculture in South Africa used 62% of the available water in the country [42]. Water use in agriculture, as a specific focus, is, however not addressed in this paper. It was therefore necessary to augment the existing value chains to represent the complete picture.

Although statistics vary between region and metropolitan areas, the main sources of drinking water in South Africa, according to the 2016 General Household Survey (GHS) [44] and categorised using the JMP ladder, are:

- *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.
- *Basic 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 m).

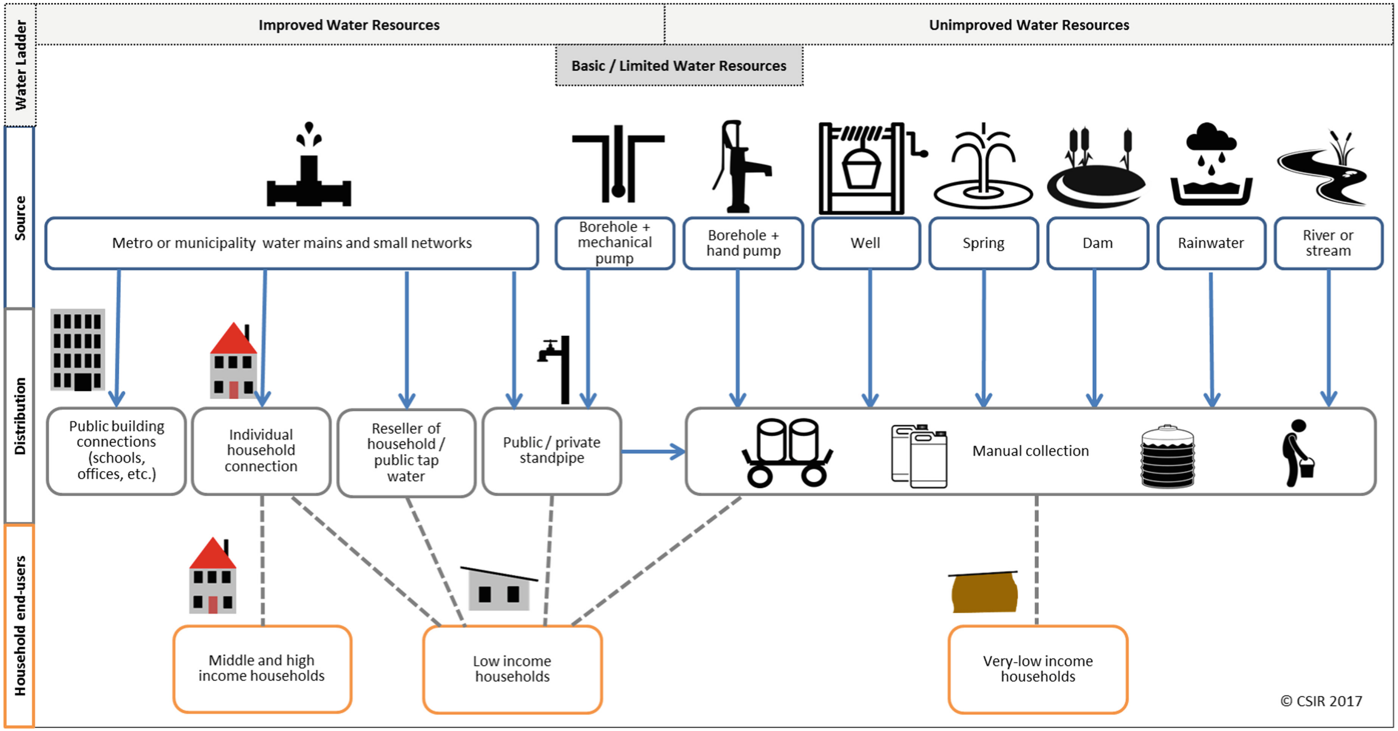

Fig. 2. Value chain for drinking water in South Africa

- *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).

Based on analysis of literature on the sources and value chains for drinking water in South Africa and Africa, is a schematic presentation of the sources of water and the diversity of water distribution in South Africa, also applicable to other African countries (see for example [45]). 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 (unimproved water), standpipes, boreholes with manual pumps (basic/limited water), or even individual connections to the 'formal' city or town water networks (improved water) [42, 45].

4.2 Sanitation Value Chain

Once the water is used/consumed, the sanitation process kicks in. 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 [46]. 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 includes six phases [47, 48]: capture of sludge, containment of sludge, emptying of sludge, transport of sludge, collection and treatment of sludge, and safe reuse or disposal of treated sanitation waste.

According to the 2016 GHS [44], 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. Despite the improved access to sanitation facilities in South Africa, the 2016 GHS [44] indicated that many households continue to be without any proper sanitation facilities.

Derived based on an analysis of literature regarding the supply sanitation practices in South Africa and Africa, Fig. 3 is a schematic representation of how the overall sanitation market works in South Africa, which is also applicable to other African countries (see for example [45]). 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 (*unimproved* sanitation), to a toilet with provision for flushing to a soak pit for the waste water (*basic/limited*

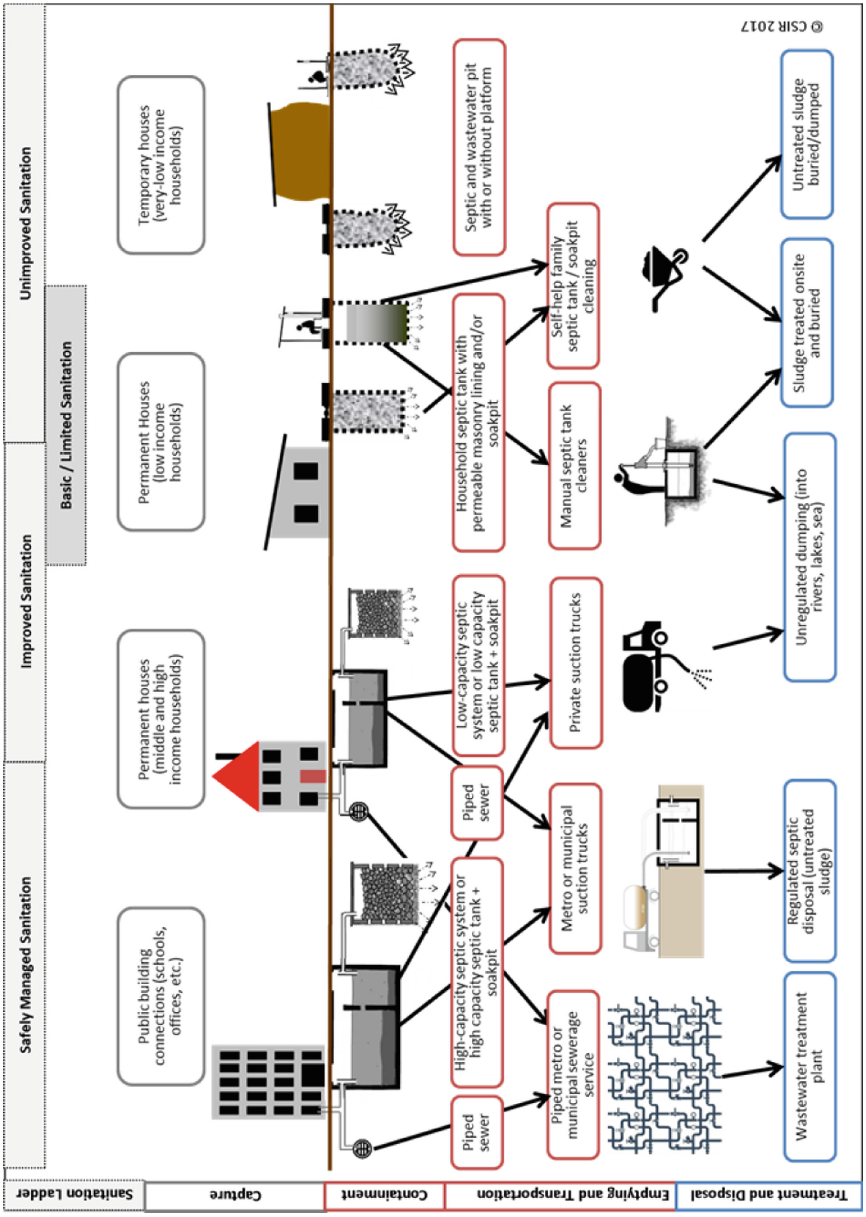

Fig. 3. Sanitation value chain for South Africa

sanitation), or, at the high end of the market, a two-stage lined septic tank and a piped sewerage system (*improved/safely managed* sanitation).

4.3 Hygiene

No value chain specifically for hygiene could be found in literature. There are, however, guidelines on when to wash hands and how to wash hands. In general hands should, for example, be washed [49, 50]: before, during, and after preparing food, before eating food or feeding children, before and after caring for an infected or 'at risk' person, after using the toilet, after changing diapers or cleaning up a child who has used the toilet, after touching an animal, animal feed, or animal waste, after handling pet food or pet treats, after handling money (or using an ATM), etc.

The Centers for Disease Control and Prevention [51] (CDC) recommends a five step process for washing hands when soap and water is available: wet, lather, scrub, rinse and dry. If soap and water are not available, CDC recommends the use an alcohol-based hand sanitiser that contains at least 60% alcohol, although it is said not to be as effective as handwashing when hands are visibly dirty or greasy and cannot eliminate all types of germs and harmful chemicals. If no soap is available or affordable, ash or mud can be used as abrasive, before rinsing [52]. Another alternative in Africa is the use of Moringa oleifera powder [53].

5 Future Scenarios for IoT in WASH

Section 3 presented insights as acquired from numerous reports, publications and a survey on the use of IoT in the WASH context in South Africa. 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 possibly bring to the WASH sector and what should be in place to increase the probability of success. The view is based on our collective learnings from literature and our experience in the WASH and IoT domain.

IoT as ecosystem enables a complete value chain, from data acquisition, processing and finally actuation with the community in the loop at all time (see Fig. 1). IoT is multidisciplinary, spanning competences ranging from device and sensor manufacturing, up to analytics and visualization techniques. However, IoT and its successful utilization span more than just technology. In driving towards a scaled IoT deployment, we therefore argue that the following aspects need to be in place to increase the chances for success in the WASH domain:

- Buy-in from the community.
- Policies for community privacy and security.
- Partnerships linked to research and the local community, vendors. and the various governing structures (e.g. the local water board).
- An established accountable ecosystem that spans technology and community.

An IoT enabled WASH environment that is operating at scale provides access to large quantities of data observations, with opportunities for in areas of big-data and analytics.

The true value of IoT is, however, only manifested when intelligent decisions are being made with the acquired data, resulting in appropriate actions. Furthermore, IoT is entirely dependent on addressing the 'real' challenge which only becomes possible if the community is part of the IoT lifecycle. 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 general benefits can be obtained:

- Better data: Data is associated with the WASH context being directly observed (e.g. water quality). Sensor data can be supplemented through community contributions/ surveys. With better data, 'evidence-based decisions' become possible.
- Better working infrastructure: IoT that enables access to the status of the WASH deployment (e.g. all devices are operational) becomes possible and thus empowers maintenance crews to effectively and rapidly service the infrastructure. Increased access to operational parameters of the devices can realise predictive maintenance.
- The context of a WASH environment will increasingly become better understood: IoT creates an opportunity for the introduction of key performance indicators that will provide insights into the operational efficiencies in WASH environments.
- Community involvement throughout the lifecycle of the WASH deployment: Having the community involved is critical and ensures that the 'real' problem is solved and not the one that appears to be the most attractive (e.g. flashy). Localised business models can be realised, e.g. an empowered local community member can be informed of required maintenance, which would allow for faster turn-around times.

Viewing IoT in relation to the United Nation's crosscutting criteria for WASH [3], several opportunities and benefits can be identified:

- Non-discrimination: Monitoring use through sensors and mobile-based technologies may assist in detecting/reporting denied or restricted access to sanitation facilities and/or water resources.
- 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 solutions, 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.

The benefits above applies to the value of IoT in a fairly broad sense. Using the WASH value chains, as depicted in Figs. 2 and 3, more focused benefits can be identified, some examples of which are listed below:

- Water quality can be measured continuously through in-situ sensors installed permanently or through 'use-once and discard' type of sensors. Data related to taste, colour and odour can be obtained. 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.

- Indicators related to water distribution can be obtained near real-time. Pressure within pipes can be measured at 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 to 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.
- Excreta management (sanitation) can be enhanced. 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 (solid) waste management can also be improved with the appropriate sensors and can be enhanced further by optimising the routing of waste trucks and the dispatch of an appropriate truck.
- Handwashing has been highlighted as one of the most important criteria for both hygiene and sanitation. IoT can be used to raise awareness of when hands should be washed. E.g. sensing when a toilet has been flushed, and if the basin has been used directly after the toilet flushing, after which a general reminder can be communicated to the occupant through smart visual aids when leaving the rest room. Also, trends from handwashing can be used as indicators of when and if additional awareness campaigns should be executed.

6 Conclusion

The study found that very limited use is currently made of IoT in the WASH domain in South Africa (and Africa). Currently the only real use of IoT related technology in South Africa is in the smart water (safely managed) management domain, primarily in metropolitan areas, to measure the amount of *improved water* use and payment therefor. No use is made of IoT to improve the livelihood and health of the majority of the South African population, and especially those dependent 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 stakeholders' 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 dependent on WASH services that cannot be classified as safely managed, improved or advanced, and to develop suitable technologies to fit such environments.

This paper was positioned to inform policy makers, improve decision-making and shape the design, implementation and commission of IoT-enabled WASH services.

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