IRC

THE HAGUE, THE NETHERLANDS | 12 – 14 MARCH 2019

All systems go!

Understanding complexity in WASH systems

Paper for the WASH systems symposium

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This paper was drafted by N. Valcourt, J. Walters, A. Javernick Will and K. Linden for the All systems go! WASH systems symposium, The Hague, The Netherlands, 12-14 March 2019.

Cite this publication as follows. Valcourt, N., Walters, J., Javernick Will, A. and Linden, K., 2019. Understanding complexity in WASH systems.

For all proceedings of the All systems go! WASH systems symposium, please check https://www.ircwash.org/proceedings

Over the past decade, the delivery of water, sanitation and hygiene (WASH) infrastructure and services has been increasingly referred to as a complex systems issue. This discourse has been followed by a call for more systems thinking tools, methods, and approaches to understand this complexity. However, while the WASH sector has a deep and rich understanding of the multitude of interconnected factors that support these services, there has traditionally been a gap in understanding how these factors interact, and how they collectively drive service delivery outcomes. Drawing from the field of complexity science, this paper seeks to provide a theoretical framing through which practitioners within the WASH sector can gain a better understanding of the dimensions of complexity and how it manifests in the delivery of WASH services. The paper provides background on the concept of complex systems, its applicability to WASH, and some proposed approaches for practitioners to use when seeking to understand and manage complexity within their local contexts.

Introduction

Water, Sanitation & Hygiene (WASH) services exist within an intricate, nuanced and often unpredictable environment of technical, social and political dimensions (Harvey & Reed, 2004; Lockwood & Smits, 2011). Within these dimensions are a wide array of factors that exert varying degrees of influence over service delivery outcomes, in addition to impacting other factors which also contribute to the success or failure of WASH services. Additionally, each of these factors has a degree of uncertainty, which changes its relationships to other factors over time, a concept known as dynamics. Thus, a complex system is a collection of interconnected factors changing and adapting over time. Yet this complexity is not unique to WASH: it is inherent in almost all aspects of life - as seen in biological systems (Camazine et al., 2003), social systems (Byrne, 1998) and economics (Arthur, 2015). Where environmental and human systems intersect, such as water resources and water service provision, complexity is expanded into coupled human-natural systems (Liu et al., 2007; Pickett, Cadenasso, & Grove, 2005). Recognising that complexity is an innate aspect of human livelihoods and drawing on lessons learned from engaging complex systems in these other domains can help the WASH sector strengthen systems and improve service delivery outcomes.

Shared learning across the WASH sector indicates that practitioners are well aware of the complex issues that influence the outcomes of their work. They can usually describe the key factors within a given context and describe how they are related to one another. When practitioners and water users describe the multitude of intersecting issues that are hindering service delivery outcomes, they are describing the complexity of a local system. But, while many of us in the sector can readily observe and describe complexity, our ability to make sense of complex problems is restricted by our bounded rationality. This refers to humans' natural cognitive limit of thinking of no more than two or three things interacting together simultaneously (Meadows & Wright, 2008), something similar to the act of juggling. Like juggling itself, as the number of factors increases in a system, so does the complexity. And as the WASH sector has continued to identify, expand and analyse the wide array of factors that lead to successful WASH service outcomes (Cronk & Bartram, 2017; Fan, Liu, Wang, Geissen, & Ritsema, 2013; Hutchings et al., 2015; Kristyna Solawetz Hulland, Martin, Dreibelbis, Valliant, & Winch, 2015; Mwangangi & Wanyoike, 2016; Samuel, Mbabazize, & Shukla, 2016), there is a critical need to improve understanding of the concept of complexity amongst practitioners and how this complexity affects the way that different stakeholders make decisions around WASH services.

Defining a WASH system

This section provides some background on key terms and basic concepts of systems, with a summary of these concepts and examples provided in Table 1.

While definitions of WASH systems abound in the sector, the tenets of what constitutes a system of factors have a long history in the field of complexity science (Bean, 1956). Ackoff (1994) simplified a system into four basic criteria:

- Two or more parts (factors)
- Each of which can affect the performance or properties of the whole,
- None of which can have an independent effect on the whole, and
- No subgroup of which can have an independent effect on the whole.

Using this definition, a system to support WASH services would be a group of factors whose collective interactions exert influence on each other, and the group as a whole, producing an overall effect that is more than the sum of the independent effects of all the factors together. This effect is often referred to as an outcome or end result of the system, such as water source functionality. In the WASH context, the outcome can represent any topic of interest such as improving water point functionality, enacting water source bylaws, or strengthening stakeholder collaboration. These outcomes can be understood as factors themselves, because they may have effects on other factors that, in turn, re-influence the outcome over time, a concept referred to as feedback (Sterman, 2009). For example, as water source functionality improves, users may be more willing to consistently pay for services, which would provide more funds for regular maintenance of the source, further improving the overall functionality.

Factors

It is important to note that factors can represent tangible, real elements of a system (e.g. hardware, tariffs, bylaws) or intangible, abstract elements (e.g. community participation, accountability, transparency). They can also represent the role that different groups of stakeholders exert on the system (e.g. mechanics, local government, water users). Considering all the dimensions of WASH services that can be represented by a factor within a larger system, one can see that there is no requirement that a factor be distinctly quantifiable or measurable. Examples of factors that are difficult to quantify can include community participation, behaviour change or political will. By delineating a boundary to the system of interest, factors in a system can further be classified as internal (endogenous) or external (exogenous) to a system. In a systems-oriented approach, identifying a boundary (real or abstract) is key to focusing in on the most important factors that are influencing a certain outcome.

Boundaries

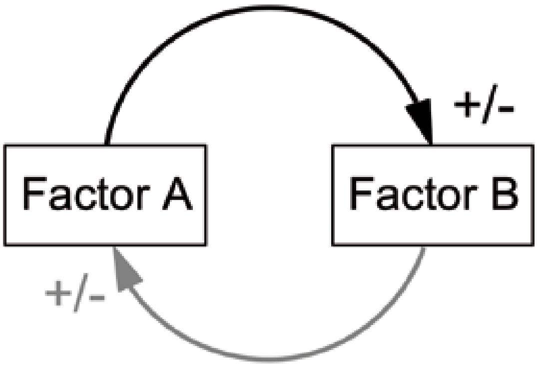
In many cases drawing a succinct boundary around an issue of interest is a necessary exercise as the number of factors that affect a particular outcome are too great in number to reasonably map or analyse (Meadows and Wright, 2008). For example, when trying to map all the factors that influence the regulatory framework for preventative water maintenance at the district or county level, one must consider whether national laws concerning water supply are as important as the role of local government and water user committees in enacting and enforcing water source bylaws. Similarly, in trying to understand the market systems that support latrine construction, decisions need to be made on how far down to follow the supply chain of materials such as concrete, rebar and squat plates. There is no one-size-fits-all approach to defining a boundary. In some contexts, the role of national government in maintenance services or international supply chains in latrine construction is more influential than in other contexts. For these reasons, a system boundary has been rightly described as a "useful fiction" (Splansky et al. 2019).

Interconnections

Identifying boundaries, and understanding which factors are most influential, only represents one aspect of a systems-thinking perspective. What makes a system truly 'systemic' is the connections, or interactions, between these factors. While there can be a multitude of important connections in any given system, it is often useful to break down these interactions into distinct factor-to-factor influences. These influences can be considered to be "pairwise", meaning that they occur in sets of two where the influence from one factor on another is independent of the opposing influence from the second factor on the first. These influences can be of a material (e.g. funds) or non-tangible (e.g. political influence) nature. A useful example of pairwise connections is illustrated by the process of WASH budget allocations; whereas a national government has the ability to allocate funding for WASH infrastructure to local governments, these local governments may have little or no input into how that allocation is determined. Through these individual direct connections, a factor can have many indirect influences on other factors within a system.

In addition to the independent nature of pairwise interactions, each factor-to-factor influence also has a dimension of polarity that represents the direction of an effect that results from the influence on it. Polarity is expressed as either a positive (cause and effect are in the same direction) or negative (cause and effect are in opposite directions) relationship. In simple terms, positive polarity means that as the condition of one factor improves, the factor that it influences will also improve. This also means that if the first factor diminishes, so too will the factor it affects. When water user committees are more accountable, for example, users are likely to be more confident that their tariffs will be used appropriately. If the committee becomes less transparent, however, tariff contributions may be expected to decline. Negative, or inverse, polarity means that as one factor improves, the other factor diminishes and vice versa. For example, as vandalism of a handpump increases in a community, functionality may be expected to decrease. If the relationship truly follows a negative polarity, then decreased vandalism would be expected to lead to increased functionality. When graphically representing pairwise interactions, polarity is expressed as a + or – sign (Fig 1).

FIGURE 1. PAIRWISE DIRECT CONNECTIONS



Source: Nicholas Valcourt

Breaking interconnections down to direct (A-B, B-C, C-D) influences, and examining the effects of strength and polarity individually, can help to systematically build an understanding of how pathways of influence can move from one factor to another through a system (e.g. A-B-C-D). When these pathways connect back to the factor at the beginning of the cause-and-effect chain, they are called feedback loops. These loops are the fundamental concept that underpins the complexity of the system, as explained below.

Table 1. Key complex systems terminology

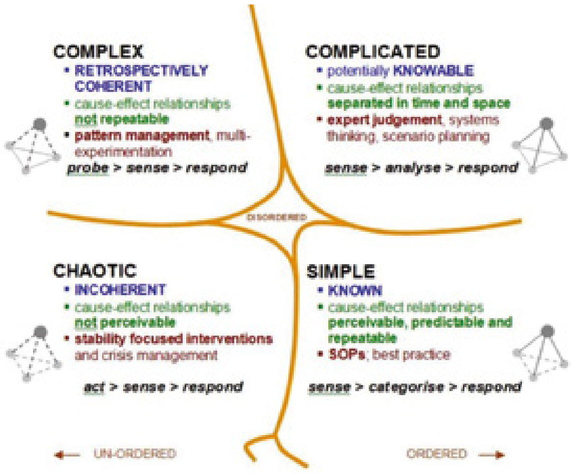
Systems Element	Definition	Example
Factor	Any element, aspect or component of the WASH service system thought to directly or indirectly influence the WASH system.	Finances, Water Resources, Government Policies, Private Sector
Outcome (Factor)	The particular factor of interest that is the focal point of the system. While any factor in a system can be the outcome factor, one must be chosen to orient a discussion or analysis around the end result of a product or service.	Water Source Functionality, Preventative Maintenance, Financing
System Boundary	A conceptual border defined for the purposes of identifying factors within a system structure which are thought to be most influential. Factors inside the boundary are considered internal or endogenous to the system, while those outside the boundary are referred to as external or exogenous. A boundary can be physical, geopolitical, organisational or abstract.	County, District, Woreda, Watershed, Town, City, Valley For a Town boundary: Availability of spare parts (internal / endogenous) Spare parts supply chain (external / exogenous)
Interactions (Direct)	The direct effect that one factor has on another factor separate from any other causes or effects from other factors within a system. These effects can be of a material or informational nature, tangible or not.	An increase in users' confidence of a Water User Committee will improve their ability to collect tariffs
Interactions (Indirect)	The indirect effect that one factor has on another factor via the interaction with a third factor.	Improving confidence of a Water User Committee will help to improve spending Preventative Maintenance (due to their ability to collect tariffs)
Polarity	The direction of correlation of an effect that the change in one factor will have on another factor to which it has a direct interaction. Positive (+) polarity implies that a change in the cause variable will result in a change in the effect variable in the same direction (If one improvews, so does the other). Conversely, a negative (-) polarity, implies that a change in the cause variable will result in a change in the effect variable in the other direction (if one improves, the other decreases).	Improving confidence in a Water User Committee leads to an increase in fee collection (positive) Declining confidence in a Water User Committee leads to a decrease increase in tariff collection (also positive) A reduction in vandalism leads to an increase in water source functionality (negative)
Dynamics	The changes observed over time in a factor and/or its interactions with other factors.	Water users' confidence in a user committee improves over time as users observe better management of their water source
Feedback	The return of material or information about the status of a factor or process that results in a change in the factor to which the information is returned. Feedback loops are the combinations of factors and interactions through which this information is feedback.	An improvement in the Water User Committee allows them to collect more tariffs, providing for better maintenance on a water source, which increases the reliable functionality of that source. This in turn improves water users' confidence in the water committee, which makes them more likely to consistently contribute tariffs towards the water source.

Complex Adaptative Systems (CAS) in WASH

The collection of factors and interactions described above does not solely create complexity that practitioners in the WASH sector observe and experience in their work. As described, these systems could be referred to as complicated, or multivariate, systems where all the factors and relationships could hypothetically be known, mapped and predicted. In contrast, complex systems are composed of factor interactions that are often dynamic, non-linear and unpredictable. These delineations of systems as simple, complicated, complex and chaotic (no order) are best represented by (Snowden, 2000) in the Cynefin Framework (Fig 2).

FIGURE 2. CYNEFINE FRAMEWORK

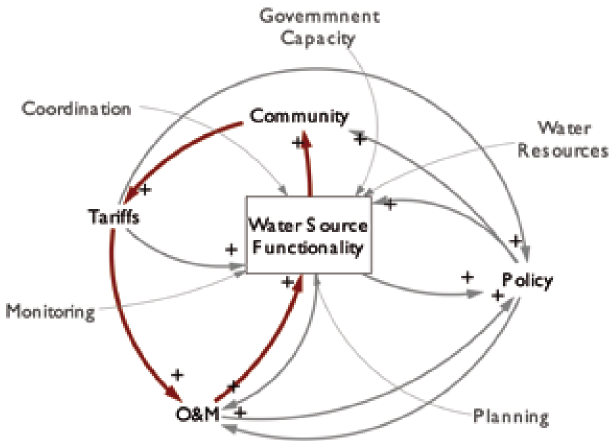
Source: Art of Social Innovation (http://aositoronto.weebly.com/cynefin.html)



In complex systems the outcome of the system (e.g. water source functionality) is the result of chains of cause and effect interactions, which form 'feedback loops' (Mitchell, 2009; Page and Miller, 2007). These feedback loops act as a pipeline for transmitting information or resources through the system. As changes propagate through the system they can come back to the factors that initiated that change, leading to further changes in the system, representing a circular causality (Richardson, 2011). In essence, each feedback loop 'tells a story' about how the combinations of factors and interactions leads to the outcomes or behaviour that the system is producing (e.g. chronically low functionality). These feedback loops can be represented by mapping the individual interactions of each factor in a system onto one another.

A common method for graphically representing these relationships is a Causal Loop Diagram (Fig 3). In this figure, the highlighted feedback loop suggests that as water source functionality improves, this will encourage the community to pay more tariffs, leading to more funds available for operation and maintenance (O&M), further improving the functionality of the water source.

FIGURE 3. CAUSAL LOOP DIAGRAM



Source: Nicholas Valcourt

This perspective of an enhanced understanding of WASH systems through feedback has been reflected in sector literature that increasingly refers to these factors and interactions as Complex Adaptive Systems (CAS) (Casella, Van Tongeren, & Nikolic, 2015; Garandeau, Bostoen, Manning-Thomas, Rogers, & White, 2009; Knipschild, 2016; Neely, 2015b, 2015a).

The concept of CAS was first developed at the Santa Fe Institute in the 1980s as a response to issues of complexity that stretched across traditional disciplinary boundaries (Waldrop, 1993). This early work framed CAS as a balance between order and disorder, where systems are composed of multiple factors and agents acting in parallel in an environment governed by norms and rules produced by those agents (e.g. stakeholders). CAS were conceived as being organised in multiple levels such that factors at one level serve as the building blocks for systems at the next level (Dodder and Dare, 2000). This conception of systems speaks to the multi-scale and multi-resolution nature that many complex systems exhibit, where smaller subsystems are embedded within, and have multiple interactions with, larger systems.

Understanding systems in this way demonstrates how these subsystems cannot easily be analysed separate from the overall system without considering the effect that exogenous (external) factors exert on the smaller system (Pruyt, 2013). Over time CAS have come to be defined by a number of unique hallmarks which set them apart from more simplistic complicated systems, including; sensitivity to initial conditions (Capra et al. 2007); path dependence (Byrne, 1998); resilience and tipping points (Meadows and Wright, 2008); feedback processes (Richmond, 1994); self-organisation; and co-evolution (Mitchell, 2009). Because of the dynamic, and often unpredictable, nature of delivering services in resource-limited contexts, CAS is a well-suited framework through which to understand the composition of factors which support or inhibit the sustainability of these services (Neely, 2015a; Ramalingam et al. 2014).

Table 2. Attributes of a Complex Adaptative System (CAS)

Complex System Attribute	Concept	Example in WASH
Sensitivity to initial conditions	Small differences in contexts where similar systems are implemented can result in markedly different trajectories over time (Mitchell, 2009)	Community Based Management (CBM) approaches could evolve to exhibit substantially different structures over time as a result of local context.
Path dependence and lock-ins	Approaches or technologies which were incorporated into the system early on, but are no longer relevant are "locked-in" to the system structure (Byrne, 1998)	Areas which were once sparsely populated are still served by individual handpumps even though use of piped systems may be more appropriate.
Resilience and tipping points	Systems tend to resist change and remain in a status quo. Some changes may be so significant they tip the system into a new normal (Mitchell, 2009)	Communities need to reduce open defecation to a critical level for there to be any public health benefit to community members.
Feedback processes	As information or resources pass from one component to another in a system 'feedback loops' of reinforcing or balancing effects begin to drive system behaviour (Richmond, 1994)	As water point functionality decreases, water users are less likely to want to pay for unreliable services, resulting in less funds for O&M which in turn further decreases the functionality of the water source.
Co-Evolution	Systems evolve together. Changes in one system can cause changes in another related system (Byrne, 1998; Mitchell, 2009)	Innovations in mobile payments can help increase tariff collection and transparency, leading to better financial accountability.

Examples of how CAS attributes are exhibited in WASH service delivery systems is presented in Table 2.

Approaches for engaging with complex WASH systems

A large suite of tools and approaches exists for understanding and working within complex systems. Reynolds and Holwell (2010) divide these tools into five groups of approaches; (1) system dynamics, (2) viable systems models, (3) strategic options development analysis, (4) soft systems methodologies, and (5) critical systems heuristics. Many of these approaches were developed in the mid-twentieth century and have evolved into a wide range of activities and analyses for engaging with complex systems. Williams and Hummelbrunner (2011) have also produced a guidebook on systems thinking methods, organised by the type of enquiry of the system structure. The authors classify these enquiries as (i) describing and analysing systems, (ii) changing and managing systems and, (iii) learning about systems. This reference guide, in addition to other works by Maani and Cavana (2004) and Masys (2016) are intended to be readily accessible to practitioners with no previous background in systems science. It is important to note that these methods need not be quantitative in nature, thus many of the techniques presented in these texts are wholly qualitative, requiring little to no computational analysis or modelling. This non-computational approach to understanding complex issues is also reflected in the increased use of a theory of change for planning systems change activities (Abercombie et al. 2018).

Regardless of the methodology employed, our review of the available tools and approaches has led us to identify **three key dimensions for stakeholders to consider when seeking to effectively engage with complex WASH issues:**

Applicability: use an approach that is 'fit for purpose'

Before jumping into an analysis or exercise consider what the goal of the systems exercise is. Systems tools can be useful for provoking discussion, aligning perspectives, identifying leverage points, designing interventions, or evaluating project outcomes. Identifying the primary goal will help determine which approach is best suited to the situation. The available inputs and intended outputs, as well as the capacity of available personnel to carry out the approach, must also be considered. Stakeholders' time, resources and skill sets are often a limiting factor in conducting complex analyses. A complicated, time-intensive tool will not necessarily lead to a better answer, and using an approach that is ill-suited to the context may actually disincentivise systems thinking if the process seems out of reach or not valuable to the intended audience. Reflecting on the end goal and the means to get there will drastically improve the outputs of the process and ensure stakeholders want to stay engaged in the approach.

Perspectives: involve multiple stakeholders

Different stakeholders interact with different components of the same systems. To get a more holistic understanding of the system, multiple perspectives are needed. Local perspectives are often overlooked and undervalued in expert analysis, particularly users and those closest to the service. Consider who interacts the most with different parts of the system and seek their input on those components. Each stakeholder brings their own 'mental model' to the table. Sharing these mental models with others helps to illuminate assumptions different stakeholders have about the way the system functions and allows a group to collectively develop a shared language for discussing complex issues.

Reflection: iteration builds learning

Systems thinking may be built on a fundamental understanding of the natural world but thinking in systems is not necessarily an intuitive skill. Improving our understanding of systems is a complex activity itself that requires time to absorb new concepts, see them in action and ultimately, shift paradigms. When engaging groups in systems thinking activities, it is important to recognise that different stakeholders learn in different ways. Information that is salient to one group can seem foreign to another. Educating stakeholders on the underlying processes of complexity, for example, may not actually help them in understanding how to deal with complexity in practice. Moreover, systems are dynamic and change over time, as does stakeholders' understanding of those systems. This is why targeted, adaptive, and repeated engagement is essential to building systems thinking skills.

Conclusion

Complexity is inherent in nearly all human and natural systems. Thus, it is an inescapable reality of the environments in which WASH services operate. Engaging in these systems therefore requires an understanding of how complex conditions can arise from the combinations of unique interactions between the components of these systems. Historical trends and new directions in the WASH sector show that this complexity is well known to many stakeholders. In any given context it is possible to identify the key factors, actors, relevant boundaries and interconnections underpinning WASH conditions through a number of existing approaches. However, the current tools available to the sector often fail to capture and illuminate the underlying structure of complexity that are the likely drivers of service delivery outcomes.

Developing a more nuanced understanding of the role of complexity, and designing effective interventions is thus essential to achieve the substantive system change the WASH sector seeks. Building this understanding is the realm of systems thinking: simultaneously a perspective, a language, and a set of tools (Monat and Gannon, 2015). In this systems thinking tool set exists a large suite of methodologies for embracing complexity, many of which require no analytical or modelling skills and can be readily adapted and applied without any prior knowledge of systems or complexity.
In practice, none of these tools are better than any other. The best approach is the one that is appropriate to the question at hand, incorporates relevant perspectives, can be effectively executed and will generate meaningful insights for all stakeholders involved. The first step is recognising the complexity, the next is making sense of it.

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Keywords

Systems thinking, complexity, feedback, factors, dynamics, complex adaptive systems, WASH

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