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Bayesian Networks as a Decision Support Tool for Rural Water Supply and Sanitation sector

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Abstract

Despite the efforts made towards the Millennium Development Goals targets during the last decade, still millions of people across the world lack of improved access to water supply or basic sanitation. The increasing complexity of the context in which these services are delivered is not properly captured by the conventional approaches that pursue to assess water, sanitation and hygiene (WaSH) interventions. Instead, a holistic framework is required to integrate the wide range of aspects which are influencing sustainable and equitable provision of safe water and sanitation, especially to those in vulnerable situations.

In this context, the WaSH Poverty Index (WaSH-PI) was adopted, as a multi-dimensional policy tool that tackles the links between access to basic services and the socio-economic drivers of poverty. Nevertheless, this approach does not fully describe the increasing interdependency of the reality. For this reason, appropriate Decision Support Systems (DSS) are required to i) inform about the results achieved in past and current interventions, and to ii) determine expected impacts of future initiatives, particularly taking into account envisaged investments to reach the targets set by the Sustainable Development Goals (SDGs). This would provide decision-makers with adequate information to define strategies and actions that are efficient, effective, and sustainable. This master thesis explores the use of object-oriented Bayesian networks (ooBn) as a powerful instrument to support project planning and monitoring, as well as targeting and prioritization. Based on WaSH-PI theoretical framework, a simple ooBn model has been developed and applied to reflect the main issues that determine access to safe water, sanitation and hygiene.

A case study is presented in Kenya, where the Government launched in 2008 a national program aimed to increase the access to improved water, sanitation and hygiene in 22 of the 47 existing districts. Main impacts resulted from this initiative are assessed and compared against the initial situation. This research concludes that the proposed approach is able to accommodate the conditions at different scales, at the same time that reflects the complexities of WaSH-related issues. Additionally, this DSS represents an effective management tool to support decision-makers to formulate informed choices between alternative actions.

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Firstly, I would like to thank my mentor and supervisor, Agustí, for the possibility to start a journey that still continues. It is not easy to enumerate all I have learnt till now by sharing uncountable, interesting, pedagogical and motivating conversations and discussions. Thanks for being engaged with the education and for encouraging people to believe that a better society can be built from their actions.

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ACRONYMS AND ABREVIATIONS

Bn	Bayesian network
CPT	Conditional Probability Table
CT	Contingency Table
DSS	Decision Support System
GoK	Government of Kenya
HH	Household
HPI	Hygiene Poverty Index
HW	Hand-washing
KNBS	Kenya National Bureau of Statistics
MDGs	Millennium Development Goals
M&E	Monitoring and Evaluation
NGO	Non-Governmental Organisation
OD	Open defecation
O&M	Operation and Maintenance
ooBn	Object-oriented Bayesian Networks
UPC	Polytechnic University of Catalonia (Universitat Politècnica de Catalunya)
SPI	Sanitation Poverty Index
UNICEF	United Nations Children’s Fund
WaSH	Water, Sanitation and Hygiene
WaSH-PI	WaSH Poverty Index
WHO	World Health Organization
WP	Water-point
WPI	Water Poverty Index
WPM	Water Point Mapping
WRMA	Water Resources Management Authority
WSB	Water Services Boards
WSP	Water Service Provider

1. Introduction

In 2000 the Member States of the United Nations signed the Millennium Declaration, which later gave rise to the Millennium Development Goals (MDGs). Goal 7, to ensure environmental sustainability, included a target that challenged the global community to halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation (WHO/UNICEF 2015).

Water and sanitation are fundamental to human development and well-being. They are not just goals in their own right but also critical to the achievement of other development objectives such as adequate nutrition, gender equality, education and the eradication of poverty (WHO/UNICEF 2015). More worrying studies affirm that diseases related to unsafe water, poor sanitation, and lack of hygiene are common causes of illness and death (Cairncross, Hunt, et al. 2010). Any intervention which aims to impact on health effectively therefore needs to integrate water and sanitation hardware with hygiene promotion (WaSH), as well as to deal with the problems of the most vulnerable segments of the population (Giné Garriga and Pérez-Foguet 2013).

Access to safe water and sanitation is also a human right, as recognized in 2010 by the United Nations General Assembly (WHO/UNICEF 2015). In 2015, even if the target for safe drinking water was met in 2010, it is estimated that 663 million people worldwide still use unimproved drinking water sources and 2.4 billion people globally still use unimproved sanitation facilities (WHO/UNICEF 2015). Undoubtedly, much effort lasts to be done. In this context, and during this year 2015, the MDGs set by the United Nations gave way to a new formulation of international action, based on Sustainable Development Goals (SDGs). The SDGs seek to complete the unfinished business of the MDGs and respond to new challenges. In this way, it was adopted the 2030 Agenda for Sustainable Development to end poverty and promote prosperity for all while protecting the environment and addressing climate change. This new Agenda also has water and sanitation at its core. The agreement of a SDG target of universal and equitable access to water, sanitation and hygiene by 2030 requires a fundamental change in the way the sector is assessed, and multi-sectoral and system-wide approaches to monitoring and evaluation are needed. They represent a shift from a reduction in the percentage of the population without access to improved water and sanitation to aiming to ensure safely managed drinking water and sanitation services for all (Targets 1 and 2 of SDG goal 6).

Globally, the vast majority of those who do not have access to improved drinking water sources and to improved sanitation facilities live in rural areas. It is estimated that 79 per cent of the people using unimproved sources and 93 per cent of people using surface water live in rural areas. On the other hand, it is estimated that 82 per cent of the urban population now uses improved sanitation facilities, compared with 51 per cent of the rural population. Seven out of ten people without improved sanitation, and nine out of ten people practising open defecation, live in rural areas (WHO/UNICEF 2015). Consequently, the provision of WaSH services has emerged as a top priority on the development agenda.

In last decades, the sector has been experiencing a decentralization of responsibilities, where decision-making moves to local administrative units and decentralized bodies assume some political autonomy. The underlying rationale for this process is that decentralized governments have an informational advantage over the central government with regard to local needs and priorities, for which reason they are assumed to supply services in accordance with demand, allocate resources more equitably, and ultimately conceive and implement policies with a focus on poverty reduction. Decentralization is also supposed to decrease corruption, as well as increase public participation and the accountability of public officials (Steiner 2007).

In this context, monitoring and evaluation are fundamental to sound decision-making; since donors, governments and civil society need objective data in which base planning, targeting and accountability mechanisms. Indicators and indices are useful tools for these purposes, and much effort has gone into the development of alternatives to evaluate WaSH issues from many disciplinary perspectives and conceptual frameworks. In this way, it is possible to find focused-approaches that tackle independently water-related (Cohen and Sullivan 2010; Sullivan 2002; WHO/UNICEF 2006), sanitation-related (Giné Garriga, Jiménez, and Pérez-Foguet 2011) or hygiene-related issues (Webb et al. 2006). On the other hand, more integrated approaches have been developed from different perspectives. As examples, WaSH-related issues have been evaluated from a Human Right point of view (Flores Baquero et al. 2013) and from a more sectoral-focused approach (Giné Garriga and Pérez-Foguet 2013; Giné Garriga et al. 2015).

Is in this last approach where this master thesis has been based. Specifically, it has been developed under the conceptual framework of the WaSH Poverty Index (WaSH-PI), introduced by Giné Garriga and Pérez-Foguet (2013). This might be defined as a holistic tool that integrates the key issues of the water and sanitation sector through an inter-disciplinary and WaSH-focused approach. At the same time, this multidimensional estimate captures the complexity inherent in rural poverty and favours the understanding to what extent WaSH issues are central to poverty alleviation.

As accurately explained by Giné Garriga and Pérez-Foguet, its theoretical foundations are built on a combination of three composites that are not aggregated to produce a single value. Rather, index components are presented individually as parts of a thematic indicator. The rationale for this is to keep the water, sanitation and hygiene idiosyncrasies in focus, as in practice institutional roles and responsibilities of WaSH issues in many developing countries are assumed by different stakeholders. Likewise, it might not be practical to merge water supply with sanitation and hygiene promotion from an operational point of view, since the latter often suffer from the budgetary dominance of water and to be effective demands a gradual implementation (Cairncross, Bartram, et al. 2010). Any aggregation process would thus reduce the validity of the measure for decision-making purposes. A brief description of each composite follows below:

i) The water-related index is founded on the Water Poverty Index (WPI) framework from Sullivan (2002) and Sullivan et al. (2003), which has been extensively applied in a variety of contexts and at different scales (Giné Garriga and Pérez-Foguet 2011; Manandhar, Pandey, and Kazama 2012; Sullivan and Meigh 2007). This composite distinguishes the broad themes that reflect major challenges in low-income regions related to water resources: physical availability of water (Resources, R_{WPI}), extent of access to water (Access, A_{WPI}), capacity for sustaining access (Capacity, C_{WPI}), ways in which water is used for different purposes (Use, U_{WPI}), and the environmental factors impacting on the ecology which water sustains (Environment, E_{WPI}). Environment-related aspects, though, are partially assessed by indicators included in the sanitation and hygiene indices; hence, this component has been removed from the WPI structure to avoid the inclusion of redundant information.

ii) The Sanitation Poverty Index (SPI) considers whether or not people have access to improved sanitation. Ideally, a toilet should be hygienic and private; accessible within, or in the immediate vicinity, of each household; available at a price that everyone could afford it; and of a culturally acceptable quality (United Nations General Assembly 2009). However, it is the consistent use of the facility, not its mere existence, which leads to health and environmental improvements (Giné Garriga et al. 2011). Therefore, SPI not only gauges the extent of access to sanitation, both in terms of accessibility and affordability (Access, A_{SPI}), but assesses people's ability to construct and repair the latrine (Capacity, C_{SPI}), and includes those hygienic factors that enable a continued usage of the facility (Use, U_{SPI}).

iii) The Hygiene Poverty Index (HPI) is measured by the aggregation of four different components (Webb et al. 2006), each one representing a different transmission route by which oral–faecal contamination may occur: drinking-water (DW_{HPI}), food (F_{HPI}), personal hygiene (PH_{HPI}); and domestic household hygiene (DH_{HPI}).

Commonly, indicators and indexes are employed to assess a specific context, to establish priorities and, based in this information available, design a battery of interventions in favour of those disadvantaged situations.

Nevertheless, this approach does not describe the increasing interdependency of the reality. For this reason, appropriate instruments are required to support decision-making with adequate information to define strategies that are efficient, effective and sustainable.

In this context, models are identified as important management tool, as these are descriptions of a real-world system that simplify calculation and prediction of outputs, given a set of inputs and parameters characterizing the model. However, although these models are highly useful for studying a vast range of problems and related impacts, in most cases they are not designed to address and integrate widely-varying aspects such as the socio-economic, legal and cultural issues.

In response to this need of more integrated approaches, and complementary to these models, Decision Support Systems appear as an alternative instrument. A DSS is a means of collecting data from many sources to inform a decision. Information can include experimental or survey data, output from functional models or, where data is scarce, expert knowledge (Bromley 2005). In other words, DSS can help structure decision processes and support analysis of the consequences of possible decision choices by making data easily accessible and allowing "what-if" analyses (Cain 2001). Specific benefits quoted in DSS studies include i) an increase in the quantity and quality of information identified as relevant to the decision, ii) an increase in the number of alternatives examined, iii) a better understanding of the management system, iv) better use of data resources, and v) improved communication and documentation of the issues and justification of decisions made.

According to these advantages, DSSs have been used in a variety of fields like medicine, artificial intelligence, road safety, etc. However, there is no evidence that the specific DSS it will be introduced in following paragraphs has been used in water and sanitation sector, embracing an integrated WaSH approach.

A Bayesian network (Bn) is a type of DSS based on a probability theory, or more specifically on Baye's Theorem, developed in 1763. Bns are directed acyclic graphs that exploit the duality between an interaction graph and a probability model (Castelletti and Soncini-Sessa 2007). The graphical structure provides a visual representation of the logical relationship between variables, established from pure theoretical knowledge, expert opinions or statistical analysis from real data. On the other hand, conditional probabilities quantify this relationship and are thus required to fully run the network. They are made up of three different elements (Bromley 2005); i) a series of nodes representing a set of variables that are relevant to the problem at hand, ii) the links between these variables which represent the existing dependency among them, and where the direction of these links express cause-effect relationships among variables, and iii) the conditional probability tables (CPTs) behind each node that are used to assess the extent to which one variable is likely to be affected by the others.

It has to be noted in this regard that the conditional probability values in the CPTs of different nodes are independent from each other, and consequently, they can be populated individually with best information available for each variable (Castelletti and Soncini-Sessa 2007). As more data or knowledge is accessed, the relevant CPTs might be updated to reflect the improved data set (Bromley et al. 2005; Castelletti and Soncini-Sessa 2007).

In this respect, Bns are powerful for incorporating data and knowledge from different sources and domains (Bromley et al. 2005; Castelletti and Soncini-Sessa 2007; Henriksen and Barlebo 2008) such as the economic, social, physical or environmental; and this key characteristic makes them particularly suited for addressing the water assessment issue in an interdisciplinary, holistic way. Similarly, this technique might be especially helpful when there is scarcity or some degree of uncertainty in the data (Bromley et al. 2005; Henriksen and Barlebo 2008). In those situations involving uncertain knowledge or when a large number of factors that is linked together need to be taken into consideration, Bns might be used to support decision-making (Bromley et al. 2005).

However, a conventional Bn is unable to receive or transmit information from outside the system (Molina et al. 2010). Instead, an object-oriented Bayesian network (ooBn) model provides a suitable framework that allows different networks to be linked together. Object-oriented networks are a hierarchical description (or model) of real-world problems that mirror the way in which humans conceptualise complex systems (Molina et al. 2010). In brief, an ooBn is a network that, in addition to the usual nodes, contains instance nodes. These nodes in effect represent an "instance" of another network, and are thus employed to import ("input" node) or export ("output" node) the information within different networks.

This master thesis explores the use of ooBn as a valid approach for supporting decision-making in WaSH planning and management, where indicators and indices are already widely used. As a remarkable advantage, ooBn offers the possibility to take a step forward. Even if indexes and indicators might be applied for the same objective but this has not been done yet, ooBn permits to provide not only with a current assessment but to infer the impact of the designed interventions or strategies.

Specifically, this master thesis focuses on the case study of Kenya, where the Government has launched a programme to improve the access to sustained water supplies, sanitation infrastructure and hygiene for the rural population in 22 districts. Taking the WaSH Poverty Index definition as a starting point, the objective of this master thesis is to demonstrate the usefulness of ooBn to inform about the foreseen impact of this initiative. It is expected to show that these networks are able to accommodate the complexities of WaSH issues, and that ooBn have the potential for wider implementation as policy tools in the context of water supply and sanitation sector.

2. Objectives

This master thesis took its first steps formulating the next research question:

"To what extent is the use of object-oriented Bayesian networks (ooBn) appropriate as a tool for supporting decision-making in water and sanitation sector?"

Once this question was set up, the overall objective of the master thesis was defined. This general objective falls on developing an ooBn as a Decision Support System which addresses the key aspects of water and sanitation sector, exploring its potentiality and under the conceptual framework of the WaSH Poverty Index (WaSH-PI).

In addition to this, three specific objectives were identified:

i) To compare the outputs provided by the use of the indexes (WaSH-PI) and the ooBn based on the same information sources, as a proxy to evaluate the validity of the latter;

ii) To assess the impacts of a WaSH-integrated intervention

iii) To evaluate potential uses of ooBn for water and sanitation sector planning.

3. Background

In the light of implementation of the WaSH Programme launched by the Government of Kenya, the issue of prioritization becomes crucial in determining the most cost-effective strategy. Water and sanitation planners and policy makers are faced with an increasing and competing demand, a variety of alternative interventions, but with limited resources. If the approach focuses on an equally universal distribution programme, this is likely to be inefficient. In contrast, to have a decision making process able to integrate the expected impact of a range of potential actions would provide managers with adequate information to define strategies that are efficient, effective, and sustainable. With this second approach, a suitable solution to assist sector-related stakeholders in predicting the effects of WaSH interventions would be the use of Bayesian networks.

As introduced, this master thesis first adopts the Water, Sanitation and Hygiene Poverty Index (WaSH-PI) framework because of its comprehensiveness to integrate all relevant WaSH issues. On the basis of this conceptual framework, a Bayesian network model is applied as an appropriate management tool. This would enable decision makers to make rational and informed choices between alternative actions during the WaSH Programme implementation mentioned above.

In this section, the theoretical background of Bns will be introduced, as well as a brief of the regional setting of the case study.

3.1. Bayesian networks

As mentioned, a Bayesian network (Bn) is a type of Decision Support System (DSS) based on a probability theory, or more specifically on Baye's Theorem, developed in 1763.

This Theorem presented a new concept in the field of probability. It can be expressed as follows: given a set of events A = {A_1, A_2, ...A_n}, where it is known the probability of occurrence, which must be different from zero; and given a random event B which the probability of occurrence is known as well as its conditional probability P (B | A_i), then the conditional probability P (A_i | B) is determined according to the following expression:

$$P\ (A_i|B) = \frac{P(A).P\ (B|A_i)}{\sum_{j=1}^{n} P\big(A_j\big).P\ (B|A_j)}$$

From this formulation, the concept of formal probability changed, emerging the possibility of generating predictable conditional probabilities from other observed events. In this way, events can be predicted from subjective data a priori. On this basis, it was developed the conditional probability, this is, estimating the probability of occurrence of an event A knowing the probability of occurrence of an independent event B.

For example, if it was known the probability of a new investment in sanitation to happen, then there would be the possibility to estimate the amount of latrines to be constructed according to the evidence regarding the latrines built up when there was a previous sanitation investment. Figure 1[1] illustrates the graphical representation of this relationship. In this way, the constructions of latrines are said to be conditionally dependant on the investment in sanitation.

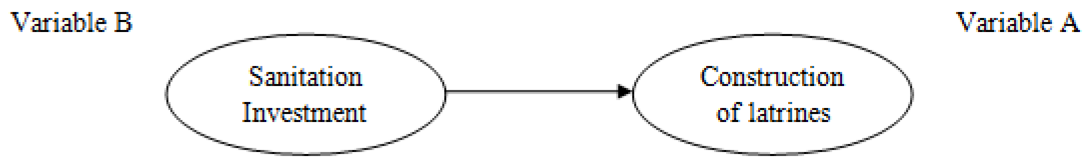


Figure 1. A simple Bayesian network represented by two variables.

As mentioned, this dependency is quantified by the associated CPT to each variable. In this way, and continuing with the example, the represented CPT in Figure 2 exemplifies the probability of the number of new latrines to be constructed (“child” node) in the light of the new sanitation investments (“parent” node). Existing evidences might suggest that if a low sanitation investment was carried out, there would be 5% of probability to construct between 2,000 and 5,000 latrines. On the other hand, if the investment was high, this probability would increase to 45%.

States of “parent” node (Variable B)

Latrines / Investment	Low	Medium	High
0 - 500	0.75	0.50	0.20
500 - 2,000	0.20	0.35	0.35
2,000 - 5,000	0.05	0.15	0.45

States of “child” node (Variable A)

Figure 2. Representation of a simple Conditional Probability Table (CPT) associated to the node “Construction of latrines”, regarding its relationship with sanitation investments.

In brief, Bns provide a visual representation of the logical relationship between variables of a system or problem at hand, while conditional probabilities quantify this relationship and are thus required to fully run the network. As it has been mentioned, the conditional probability values in the CPTs of different nodes are independent from each other, and consequently, they can be populated individually with best information available for each variable (Castelletti and Soncini-Sessa 2007). For each variable the tables express the probability of that variable being in a particular state, given the states of its parents.

However, a conventional Bn is unable to receive or transmit information from outside the system (Molina et al. 2010). Instead, an object-oriented Bayesian network (ooBn) model provides a suitable framework that allows different networks to be linked together by using the so called instance nodes. These nodes in effect represent an “instance” of another network, and are thus employed to import (“input” node) or export (“output” node) the information within different networks. In an ooBn, the following notations are used: input nodes are ellipses with shadow dashed line borders and output nodes are ellipses with shadow bold line borders.

[1] All Figures and Tables in this master thesis were elaborated by the author, unless the opposite is specified.

Figure 3 represents the observations highlighted. In order to illustrate them, partial extractions from three different sub-networks were considered; "Water Supply Capacity" sub-network (upper-left extraction), "Water Supply" sub-network (upper-right extraction) and "Hygiene" sub-network (bottom extraction). As it can be seen, issues related to the maintenance of water-points (upper-left extraction) have a direct impact in sanitary conditions of these systems ("Sanitary risk" node, upper-right extraction). On the other hand, aspects related to water quality and time spent to fetch water (upper-right extraction) affect other variables regarding hygiene-related aspects.

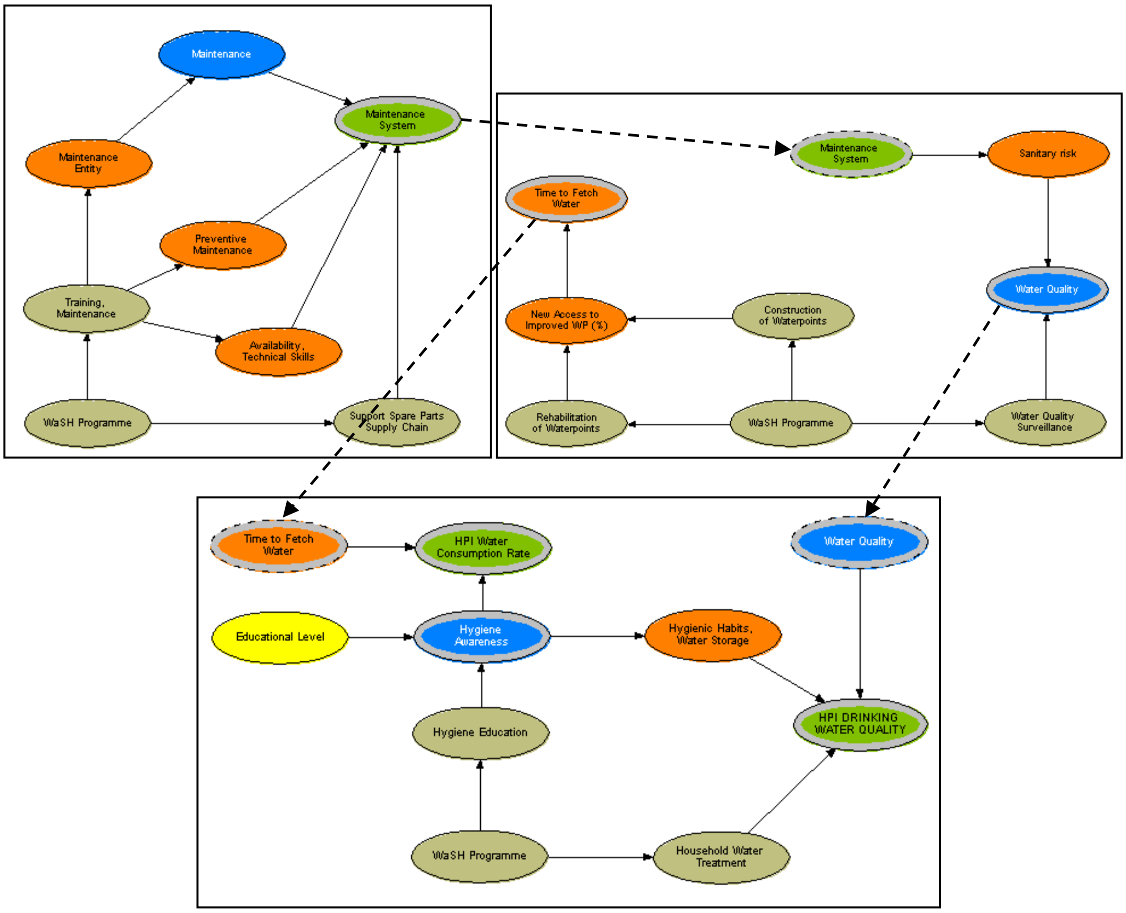


Figure 3. Representation of the rationale of an ooBn. Upper-left: an extraction of the "Water Supply Capacity" sub-network; Upper-right: an extraction of the "Water Supply Capacity" sub-network; Bottom: an extraction of the "Hygiene" sub-network. Discontinuous-lines represent conection between networks.

3.2. Case study

Kenya has an estimated population of roughly 38 million, with more than three quarters of people residing in rural areas (Kenya National Bureau of Statistics 2009). According to the last Kenya Demographic and Health Survey (Kenya National Bureau of Statistics (KNBS) and ORC Macro 2010), less than two thirds of the people (60.2 %) use improved sources of drinking water, and only 24.3 % of the population have access to adequate sanitation facilities. The situation in rural areas is below the national average (53.1% and 21.8% respectively), and since regional disparities are marked, large number of rural districts does not even reach these coverage ratios. Water and sanitation related diseases are contributing to high mortality of children under five, which stands at 74 per 1,000 children. Diarrhoeal diseases might cause about 20 % in high-risk areas (Kenya National Bureau of Statistics (KNBS) and ORC Macro 2010). Within this high-risk environment, the Government has identified through a consultative process with primary stakeholders the vulnerable populations living in rural areas, where access to safe drinking water and sanitation is particularly acute (United Nations Children's Fund and Government of Kenya 2006). This master thesis focuses on these populations.

Against this background, the Government of Kenya in collaboration with UNICEF have launched, with support from the Dutch Government, the Programme of Cooperation "Acceleration of Water Supply and Sanitation towards Reaching Kenya's Millennium Development Goals (2008 – 2014)". This initiative is aimed at increasing the access to improved water, sanitation and hygiene in 22 districts (see Figure 4), contributing to the achievement of the sector-related Millennium Development Goals.

District	Population	HH	Area (km^2)	Density	Climate
Bondo	157,522	37,296	593.0	265.6	
Busia	327,852	68,781	681.0	481.4	
Garissa	190,062	32,118	5589.0	34.0	Arid
Isiolo	100,176	22,463	15517.0	6.5	Arid
Kajiado	549,816	143,761	15490.0	35.5	Semi-aird
Kieni	175,812	201,703	3337.0	52.7	Semi-aird
Kisumu	618,556	148,494	918.0	673.8	
Kitui	447,613	94,780	7616.0	58.8	Semi-aird
Kwale	151,978	28,559	1031.2	147.4	Semi-aird
Mandera	1,025,756	125,497	25991.0	39.5	Arid
Marsabit	46,052	10,005	2052.0	22.4	Arid
Mwingi	244,981	50,967	5224.3	46.9	Semi-aird
Nyando	350,353	78,225	1168.0	300.0	
Rachuonyo	382,711	81,395	950.7	402.6	
Siaya	550,224	130,705	1534.0	358.7	
Tana River	143,411	28,624	22822.9	6.3	Arid
Turkana	855,399	123,191	68680.0	12.5	Arid
Wajir	661,941	88,574	56686.0	11.7	Arid
West Pokot	181,063	93,777	9169.0	19.7	Semi-aird

Table 1. Population (total and number of households), area, density and rainfall of intervened districts. Source: (Giné Garriga and Pérez-Foguet 2013; Kenya National Bureau of Statistics (KNBS); ORC Macro 2010).

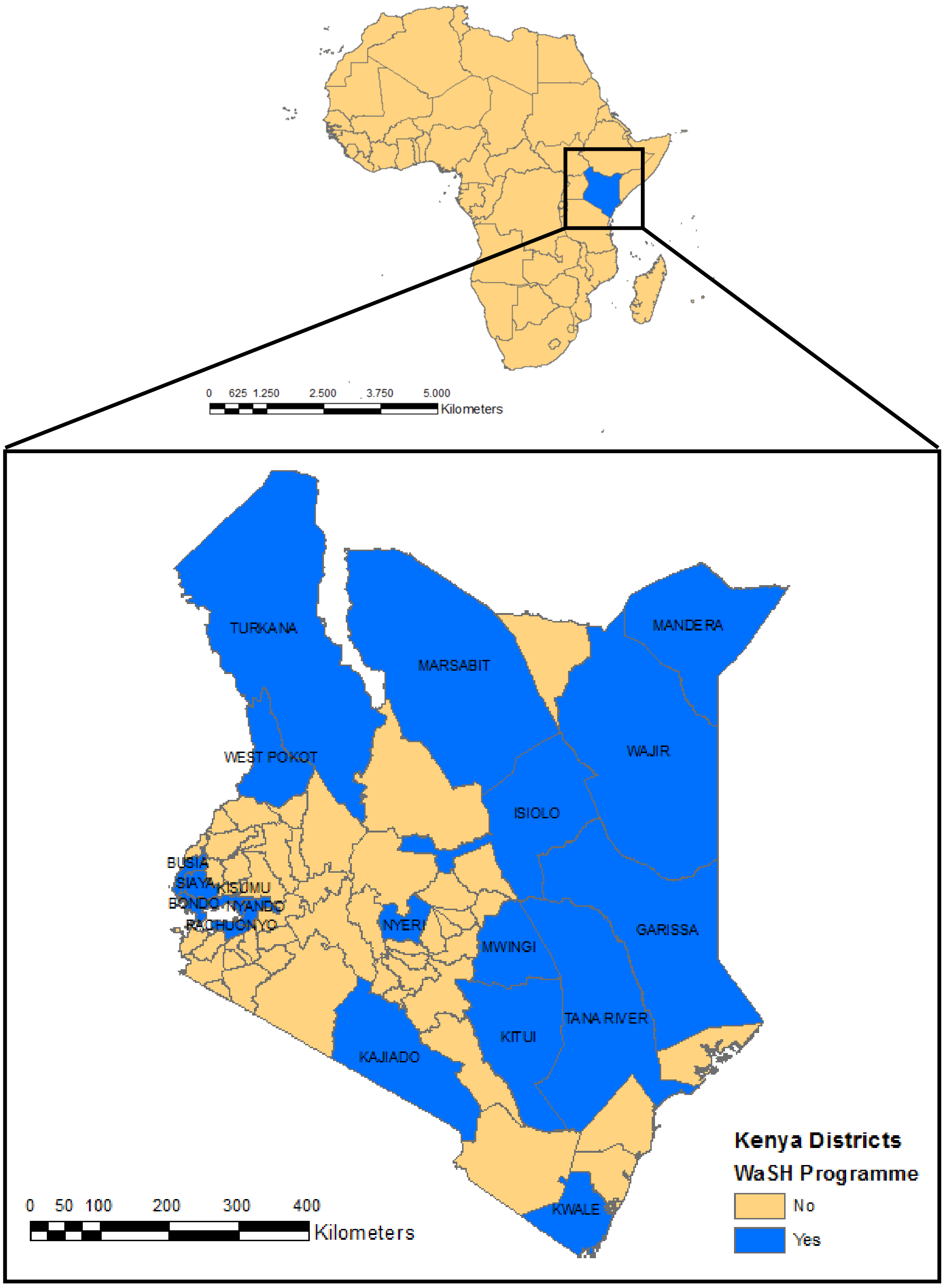


Figure 4. Kenya's intervened districts by the WaSH Programme (in blue).

To inform policy development, the situation in relation to WaSH was assessed through a cluster sampling household-survey, conducted during 2010 (from January to March). The survey showed that only 43.5 % of households got their drinking water from an improved source. And besides coverage data, it was seen that a large percentage of people (45.4 %) spent more than half an hour per round trip to collect water. Since distance showed a negative association with water consumption, it was not rare to observe that almost two thirds of households (62 %) did not meet their minimum daily drinking-water needs (less than 20 l per capita per day, based on WHO standards). Another remark with regard to water collection was related to gender disparities, since by and large it was women (87 %) who went to the source to haul water for domestic purposes. In terms of sanitation coverage, data showed an alarming situation, averaging only 21.6 % for the whole survey. Among those who did not use an improved facility, latrine sharing was a common practice (33.7 %), although the majority of households (41 %) opted to defecate in the open. As regards personal and domestic hygiene, the survey revealed that household water treatment was to certain extent common throughout the area of intervention, since almost half of households (47.1 %) adequately treated water before consumption. Another hygiene behaviour which is of greatest likely benefit to health related to safe disposal of the stools of children under age three; and on average 58.1 % of children's faeces were disposed of hygienically. Finally, it was noted that almost everyone washed their hands, although both the method employed and hand-washing frequency was inadequate.

The project mentioned above consisted in an integrated water, sanitation and hygiene programme which supports the water, education and sanitation reforms. The main goal was improving child survival rates and development through using sustainable safe water and sanitation facilities and practicing good hygiene. In parallel, the project targeted poor people living in rural areas that currently did not use safe drinking water and/or, sanitation facilities and did not practice appropriate hygiene; especially hand washing. The use of sustainable and affordable safe drinking water was expected to reduce direct and indirect health costs to both households and to the Health Services and was thought to contribute to reduce opportunity costs to households.

This WaSH Programme was expected to achieve the following outcomes, organized according to the structure that will be introduced in Section 4.2:

Intervention	**Outcome**
Institutional capacity	1.900 people will be trained to strengthen institutional frameworks able to assist communities with regard to water point management
Training in management	4.147 community groups and service providers will be trained in water-point management issues
Training in maintenance	4.147 community groups and service providers will be trained in water-point operation and maintenance issues
Support to spare parts supply chain development	At least 1 action will be taken in every intervened district to improve spare parts supply

Table 2. Expected outcomes from the WaSH Programme, according to water supply capacity-related interventions. Source: (GoK and UNICEF 2006).

Intervention	Outcome
Construction of water-points	1.3 million of people will use new safe and sustainable sources of drinking water (25 litres per person per day obtained within 30 minutes round trip)
Rehabilitation of water-points	310,000 people will use newly rehabilitated safe and sustainable sources of drinking water (25 litres per person per day obtained within 30 minutes round trip)
Promotion of multiple use of water	At least 1 action will be taken in every intervened district to promote multiple uses of water
Water quality surveillance	At least 1 action will be taken in every intervened district to improve water quality surveillance and monitoring

Table 3. Expected outcomes from the WaSH Programme, regarding water supply-related interventions. Source: (GoK and UNICEF 2006).

Intervention	Outcome
Hygiene education	70 per cent of 1.95 million new practitioners will adopt appropriate hygiene practices. Hygiene education to households will be carried out through direct marketing
Household water treatment	70 per cent of 1.95 million new practitioners will practice point of use water treatment, safe water storage and hygienic handling of water. This intervention will be carried out through direct marketing
Hand-washing promotion	70 per cent of 1.95 million new practitioners will adopt appropriate hand-washing practices. This intervention will be carried out through direct marketing as well

Table 4. Expected outcomes from the WaSH Programme, according to hygiene-related interventions. Source: (GoK and UNICEF 2006).

Intervention	Outcome
Sanitation	
Construction of latrines	1.6 million people will use newly constructed hygienic toilet facilities with hand washing facilities at household level
Implementation of local production units	1800 local component production units will be set up
Training in sanitation technical skills	3000 community sanitation promoters will be trained in construction of sanitation facilities

Table 5. Expected outcomes from the WaSH Programme, regarding sanitation-related interventions. Source: (GoK and UNICEF 2006).

4. Methodology

As a starting point, it should be mentioned that an extensive literature review was carried out in order to establish a suitable conceptual framework of analysis and to support the statements provided, giving the opportunity to the author to complete a successful immersion into a deep understanding of water and sanitation sector and its links with aspects that embrace from social and political issues to more technical ones.

On the other hand, an original methodology, in terms of the master thesis' field, was selected to be tested. This point represented a challenge but the existing literature provided useful information to understand the potential of Bayesian Networks. However, it has been comprehended that more powerful technologic tools would be required in order to take advantage of the full potential of this Decision Support System.

After these introducing lines, in this Section it will be dealt with the development and conceptualisation of the object-oriented Bayesian networks (ooBn). Firstly, a detailed description of the key aspects to construct the networks is provided. Secondly, a broad outline of the different networks will be given, accompanying this explanation with a deeper contextualization of the case study.

4.1. Development of Networks

This section deals with the development of an ooBn to be used as a decision support tool. In particular, the aim was to build a network to help assess the impact of the implementation of the WaSH Programme mentioned in previous sections. To this end, the assistance of a technological platform aiming to help in all computational calculations was required. Although, free software was available for building up Bns (namely "R", www.r-project.org), a commercial software package produced by HUGIN (www.hugin.dk) has been used. The main reason fell on the advantages that the latter offers. These features, regarding the graphical user interface, can be detailed as follows:

i) Construction, maintenance and usage of knowledge bases using Bayesian networks and Influence diagrams technology;

ii) Supports development of object-oriented Bayesian networks;

iii) Interface to automated learning of Bayesian networks from databases;

iv) Wizard for generation of probability tables.

Once introduced the technological support chosen, the rest of the section deals with the three key steps required for the construction of ooBn.

4.1.1. Identification of variables and definition of links

In this first step, the identification of the variables relevant to the problem and definition of key linkages among them was carried out. To assess the level of WaSH Poverty, the ooBn were divided into four sub-networks and a master network to represent the three composites of the WaSH-PI. A large number of variables (99) were identified and classified based on their nature (Bromley 2005): "Objectives" are those variables the Programme aims to improve, and are depicted graphically in green; "Interventions" are all the actions to be implemented through the Programme to achieve these objectives (in grey); "Intermediate Factors" are all the elements that link "Objectives" and "Interventions" (in blue, sectoral factors with constant values independent of geographical scale of application, and in orange, contextual nodes with values conditioned to the geographical scale considered); and "Controlling Factors" (in yellow) are other variables which somehow influence the system but cannot be controlled. Finally, it is remembered the existence of output nodes (ellipses with shadow bold line borders), and input nodes (ellipses with shadow dashed line borders). Table 6 and Figure 5 summarize these considerations:

Sub-network	Num. of variables	Category				
		Objective	Interven.	Interm. Fact. Sectoral	Interm. Fact. Contextual	Control. Factor
Water Supply Capacity	23	3	5	4	11	---
Water Supply	32 (2)	4 (1)	5	9	13 (1)	1
Hygiene	23 (2)	5	4	5 (1)	8 (1)	1
Sanitation	21 (1)	3	4	5 (1)	8	1
Total	99	15	18	23	40	3
Note: In brackets, number of input nodes						

Table 6. Classification of variables at sub-network level.

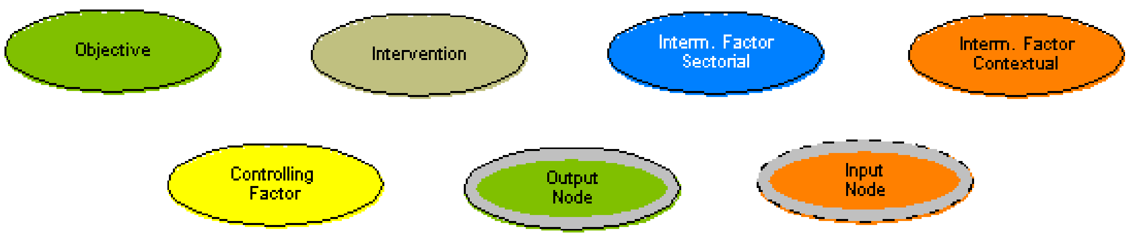


Figure 5. Node classification graphical representation.

4.1.2. Data Collection

Next step fell on collecting the data for the probability tables that lie behind the variables. A key part of the process was to make sure that the tables constructed for each variable were based on the best information available. Trying to influence and support decision-makers when the information provided is scanty or inaccurate would lead to meaningless results.

As it has been mentioned previously, the Programme of Cooperation “Acceleration of Water Supply and Sanitation towards Reaching Kenya’s Millennium Development Goals (2008 – 2014)” was launched by the Government of Kenya in collaboration with other international actors. This information represented the starting point as it facilitated both the objectives and the approach of the project. In this way, it was possible to assess the impacts of this initiative, as well as giving support for further discussion.

On the other hand, the Programme carried out a WaSH-related baseline as to evaluate the situation of the intervention area. The approach adopted for data collection combined a water point mapping with a stratified survey of households, both of them conducted by the Polytechnic University of Catalonia (UPC) in close collaboration with government’s technicians. Key features of the mentioned methodology included i) an exhaustive identification of enumeration areas (administrative subunits as communities, villages, etc.), ii) audit in each enumeration area of all improved and unimproved water points accessed for domestic purposes, and iii) random selection of a sample size of households that was representative at the local administrative level (e.g. district, municipality, etc.) and below (Giné Garriga, Jiménez, and Pérez-Foguet 2013).

In detail and regarding these information sources, the household-survey provided with key information related to WaSH issues and socio-economic aspects. Regarding the 22 intervened districts, 5050 household were monitored, involving 351 locations. In parallel, the water point mapping supplied management, technical and demographical information from all water points gathered (improved and unimproved). As regard the intervened districts, 407 water points were monitored, involving the locations mentioned above (see Annexe II for more information).

However, it has been noted that available data has been insufficient to accurately assess some nodes, and further refinements to the networks would be required in this regard.

4.1.3. Assignment of the states and completion of the conditional probability tables

Once the variables were defined and grouped, their states and probabilities were assigned using available data or expert knowledge. The conditional probability tables (CPTs) are the core of the network since it is their values that will determine the outcomes, and thus special care should be given to this stage. For each variable the tables express the probability of that variable being in a particular state, given the states of its parents. The complexity and size of the CPTs depends on the number of parents and the number of states the respective variable has (Bromley 2005). It is, therefore, advisable to construct the network with a limited number of parents and states, as the CPTs become much more manageable.
Regarding the states of the variables, it should be mentioned the different ways these can be described:

i) As a set of labels; e.g. good, acceptable, poor.
ii) As a set of numbers; e.g. 1, 10, 100
iii) As a set of intervals; e.g. 0 - 0.5, 0.5 - 0.75, 0.75 - 1
iv) In Boolean form; e.g. true, false

As introduced in section 3.1, a brief description of how a simple CPT is constructed was given. Nevertheless, it is presented the four remarkable aspects that can be differentiated in order to populate the CPTs (see Annexe I for a detailed explanation of every CPT development):

i) Transformation of the WaSH Programme outputs into ooBn's inputs

A key process in the development of the ooBn was the establishment of those CPTs corresponding to the "Intervention" nodes, as these are the main inputs to assess the impact of the Programme.

As an easy example, it is presented how the CPT of the node related to the hand-washing promotion was constructed. The associated intervention establishes that after the project completion, 70 per cent of 1.95 million new practitioners would adopt appropriate hand-washing practices, especially hand washing with soap (or ash) at key occasions. In this way, there are two scenarios: before and after the WaSH Programme.

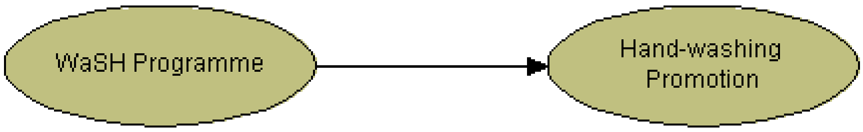


Figure 6. Representation of one of the interventions of the WaSH Programme.

Current situation was assessed considering those people who have attended a meeting or training within the last year as a positive scenario (state: 1). More than one year was taken into account as a negative one (state: 0). Data was obtained from the household survey mentioned previously (see Annexe II). According to Table 7, approximately 13% of the population interviewed had attended such training. In this way, CPT presented in Table 8 was populated with this value for the "state 1", associating the rest 87% to the "state 0".

HPH_Hygiene Promotion

		Frecuencia	Porcentaje	Porcentaje válido	Porcentaje acumulado
Válido	< 1 month ago	198	3,9	3,9	3,9
	1 month - 1 year ago	436	8,6	8,7	12,6
	> 1 year ago	332	6,6	6,6	19,2
	> 5 years ago	95	1,9	1,9	21,1
	Never	3979	78,8	78,9	100,0
	Total	5040	99,8	100,0	
Perdidos	Don't know	10	,2		
Total		5050	100,0		

Table 7. Data available regarding the population who have attended a training in hygiene promotion.

On the other hand, and considering that the target population is 7,253,941 people (Kenya National Bureau of Statistics 2009), those new beneficiaries mentioned before (70% of 1.9 million people, which is equal to 1.3 million inhabitants) represented the 19% of the total. In this way, this expected value after project completion was added to the existing one regarding the “state 1”. Thus, the final value would be 13% + 19% = 32%. Accordingly, people who wouldn’t attend this short of training would be reduced to 68% (see Table 8).

Graphically, the CPT could be presented as follows:

	No WaSH Programme	**WaSH Programme**
0	0.87	0.68
1	0.13	0.32

Table 8. Representation of a simple CPT.

Regarding other “Intervention” nodes, different assumptions and calculations were done (see Annexe I).

ii) Introducing the evidences of existing events

Probably, this process might be defined as the core of the ooBns, as the existing evidences of any event will determine the outcomes of the networks.

Considering the example of the training in management that would be provided to the community groups responsible for the water-points, it was considered that this fact would encourage their legal registatrion.

Figure 7. Representation of one of the WaSH Programme interventions and causal related node.

The manner that the “Training, Management” node was constructed follows the previous example. On the other hand, to assess “Registration” node, contingency tables (CT) were developed extracting the information needed, in this case, from the Water Point Mapping survey. A CT is a type of table in a matrix format that displays the (multivariate) frequency distribution of the variables (in this case, nodes and their parents). They provide a basic picture of the interrelation between two variables and can help find interactions between them. These operations were facilitated by the use of the statistical software SPSS. In this example, it was possible to determine how many community groups were registered, regarding whether they received any training in management or not.

In this way, and according to these evidences, it is possible to simulate two different scenarios, before and after the WaSH Programme, and to get the outcomes associated to them.

	No WaSH Programme	**WaSH Programme**
No training received	0.79	0.65
Training received	0.21	0.35

	No training received	**Training received**
No registered	0.45	0.18
Registered	0.55	0.82

Figure 8. Representation of CPT construction, visualizing the relationhip between "parent" and "child" nodes.

iii) Evaluating the relative importance of nodes in case of the existence of several parent nodes

As not always there is a linear causal relationship node-to-node, there are situations where one node can be affected by several parents nodes. In this situation, a more complex definition of the CPT shows up.

In order to illustrate this case, it is presented the case where node "Revenue Collection, Effectiveness" (RCE) is conditioned by nodes "Payment System" (PS) and "Financial Control" (FC).

Considering that PS has a probability x = 75% to be in place and FC has a probability y = 75% to be carried out. Furthermore, establishing that the existence of a PS is two times more important than FC, then the cross probability in order to populate the CPT would be:

RCE = (2/3). PS + (1/3). FC

PS = FC = 0; [0.66.(1 - x)] + [0.33.(1 - y)] = 0.25
PS = 0, FC = 1; [0.66.(1 - x)] + [0.33.y] = 0.41
PS = 1, FC = 0; [0.66.x] + [0.33.(1 - y)] = 0.58
PS = FC = 1; [0.66.x] + [0.33.y] = 0.75

	Payment System	**0**		**1**	
	Financial Control	**0**	**1**	**0**	**1**
RCE	**0 - 0.25**	1	0	0	0
	0.25 - 0.50	0	1	0	0
	0.50 - 0.75	0	0	1	0
	0.75 - 1	0	0	0	1

Table 9. Representation of a more complex CPT, where PS and FC are the parent nodes of RCE.

Obviously, such a task, when there are a higher amount of parent nodes, becomes complex and daunting. Fortunately, the software permitted to obtain the results just providing the relative importance of the parent nodes. In this master thesis, some considerations were supported by literature review and expert knowledge.

i) Not conditioned nodes

Last but not least, there were nodes not conditioned by other nodes. In this case, the CPTs are simple and don't imply a relationship with any parent node. The way to populate the CPT was straightforward and it was just needed to provide existing evidences from the data bases.

As an example, it is shown the "Educational Level" node. This node considers those households' heads with primary studies completed (state: 1). The CPT is represented as follows:

	Educational Level
0	0.66
1	0.34

Table 10. An example of not conditioned CPT.

4.1.4. Sensitivity analysis and robustness of the networks

A sensitivity analysis is the study of how the uncertainty in the output of a mathematical model can be apportioned to different sources of uncertainty in its inputs.

In this master thesis, it was considered suitable to carry out the process of recalculating outcomes under alternative assumptions, as a first step to test the sensitivity of the networks. It is well known, that further efforts must be employed in this regard. Nevertheless, and considering that a model was developed, it was thought that, at least, some operations must have done.

On the other hand, the robustness of the network was tested, as a complementary task to the mentioned above. To do this, it was focused on those variables where the opinion of experts played a key role, as there was a higher degree of data uncertainty and the relative importance among indicators was set up. In this way, a set of nodes were selected, model disturbances were carried out and results of key variables were assessed.

In Section 5.4, results regarding these processes are presented and discussed.

4.2. Conceptualisation of the networks

In this section, it will be dealt with the conceptualisation of the networks. As mentioned, the ooBn is based on the conceptual framework of the WaSH-PI, introduced by Giné Garriga and Pérez-Foguet (2013), and whose theoretical foundations are built on a combination of three composites that are not aggregated to produce a single value (see Table 11).

Composite	Component	Indicators
Water Poverty Index (WPI)	WPI - Capacity (3)	*% of households involved in water-point management*; management of the water-point (user perception); *and % of households contributing to the maintenance of the water-point*
	WPI - Resources (2)	Availability of water for domestic purposes; % of households using their main drinking-water source all year-round; and water quality (user perception)
	WPI - Access (4)	% of households with access to improved water-points; time spent in fetching water; *% of water carried by woman or children under 15*; and payment for water (user satisfaction)
	WPI - Use (2)	Domestic water consumption rate; % of households using main drinking-water source for other domestic purposes;
Sanitation Poverty Index (SPI)	SPI - Access (2)	% of households with latrine because of lack of economic resources (affordability issues); and % of households accessing a toilet facility in the same compound
	SPI - Capacity (2)	% of households with no latrine because of a lack of capacities to construct; and % of households accessing adequate skills for repairing the latrine;
	SPI - Use (2)	% of households using improved sanitation facilities; and latrine sanitary conditions
Hygiene Poverty Index (HPI)	HPI - Drinking water (2)	% of households correctly handling and storing drinking water; and % of households with an adequate point-of-use water treatment
	HPI - Food hygiene (2)	% of households with a drying rack for plates and cups; % of caregivers who wash their hands at critical moments
	HPI - Personal hygiene (4)	% of caregivers correctly handling baby excreta; % of households with an adequate hand-washing device around the latrine; % of households whose members participated in hygiene promotion campaigns; and % of caregivers with adequate hand washing behaviour
	HPI - Domestic hygiene (2)	Animals running around freely in the compound; and compound swept on day of visit

Note: In bracket, number of identified indicators. In italics, indicators not considering for the construction of ooBn

Table 11. Composites, components and indicators considered in the underlying structure of the WaSH-PI. Source: (Giné Garriga and Pérez-Foguet 2013).

In this way, four different sub-networks and a master network were developed in order to keep in focus the different components related to the three composites, as the formers are considered key aspects to take into account when dealing with WaSH-related issues. In fact, as introduced in section 4.1.1, these aspects were defined as “Objective” nodes. However, as showed in that section, the underlying indicators considered in ooBn are higher in number.

In order to understand following sections, in Table 12 is detailed how both approaches are linked together.

Composite	Component	Sub-network
Water Poverty Index (WPI)	WPI - Capacity	*Water Supply Capacity*
	WPI - Resources	Water Supply
	WPI - Access	Water Supply
	WPI - Use	Water Supply
Sanitation Poverty Index (SPI)	SPI - Access	Sanitation
	SPI - Capacity	Sanitation
	SPI - Use	Sanitation
Hygiene Poverty Index (HPI)	HPI - Drinking water	Hygiene
	HPI - Food hygiene	Hygiene
	HPI - Personal hygiene	Hygiene
	HPI - Domestic hygiene	Hygiene

Table 12. Relationship between the WaSH-PI components and ooBn sub-networks.

On the other hand, and taking into account that providing a detailed explanation of each individual variable is not feasible, only a broad outline of the different sub-networks will be given. Nevertheless, this description will be accompanied with a deeper contextualization of the case study.

4.2.1. Water Supply Capacity

The poor performance of centrally managed rural water supply programs implemented in the past has caused a shift towards local governance and a more user-centred approach to development, based on popular participation (Khanal 2003). The underlying theory is that meaningful and rapid development is best achieved through a decentralization process (Maro 1990); i.e. devolution of responsibility for water schemes from governments to villagers, through a participatory approach involving users, planners and policymakers at all levels. There is evidence that it can only be achieved through a variety of institutional arrangements.

In this respect, the Kenya Water Act (2002) provides for a decentralized structure to separately improve water resources management and water services provision. The Act establishes an autonomous Water Resources Management Authority (WRMA), destined to manage and protect Kenya’s resources. It also shapes an adequate institutional sector reform that give responsibility for providing decentralised services to regional Water Services Boards (WSB).

The new framework adopts a demand based approach where the communities will take leadership in planning, preparing proposals, implementation and post-completion maintenance and management of their water and sanitation facilities. To this end, WaSH Committees are created to represent the users. The Programme is also aimed at developing community ownership over the water schemes, even though there is no clear consensus on whether this “sense of ownership” should be a prerequisite for community management (Doe and Khan 2004; Giné Garriga and Pérez-Foguet 2008). The Water Service Boards in turn are committed to manage water supplies assets and provide capacity building support to create an enabling environment that promotes user participation. In short, these boards are responsible for appraising the community proposals and contracting during the implementation activities. After project completion, they need to regulate Water Service Providers as well as to monitor the sector.

The Water Service Provider (WSP) will be responsible for operating and managing water supplies. They may be from the private sector, NGOs, CBO, and others. In this respect, community groups may also apply to the WSB to be licensed as a WSP; and particularly the registration of women groups is to be encouraged to establish an effective community based management system of the schemes, since it has been shown elsewhere (GoK and UNICEF 2006) that water-points managed by women groups perform the best.

The biggest challenge nonetheless lies within the capacity of all these new institutions to perform as expected and lead in revitalising the water sector. Thus, emphasis should be placed on building up capacities of the recipient organizations, and on institutional support from the Government and non-Governmental organizations. At present, not all the communities are equally prepared to efficiently fulfil their responsibilities; and local authorities lack strategic oversight. Another constraint is low levels of literacy, which directly affects effective operation and maintenance of water facilities.

Equally important, the problem of supplying spare parts in rural areas for water schemes and the availability of technicians needs to be highlighted. Despite the robustness of the private sector in Kenya, it is not uniformly strong in water, sanitation and hygiene related supplies and services in the different districts of the country. Such gaps are currently filled through sourcing from neighbouring districts or from Nairobi, the capital of the country. Therefore, private sector capacity building and development of a reliable supply chain needs to be supported to ensure sector skills and spare parts availability when the need arises; minimizing the time required repairing the scheme and thus improving its effectiveness.

The Water Supply Capacity sub-network

This network (Figure 9) aims to represent all key variables that determine to what extent the decentralization process is to be favoured throughout the WaSH Programme. Thus, its structure clearly is ordered regarding the interventions that might influence the state of key variables ("Objective" nodes).

The first group of nodes (left-half of the network) focuses on the institutional framework required to properly assist the communities with regard to the water-point management. At the same time, it focuses on management issues that comprise aspects of organization (e.g.: management entity and entity's inner performance), gender equity and even user perception. Integral to this first set of variables, an assessment of the community financing strategies appears essential, to understand which mechanisms are in place for revenue collection that contribute towards the cost of running the water supply.

The second group of variables (right-half of the network) determines the status of the supply of equipment and spare parts in the local markets, as well as technical skills and capacities. Both aspects are required to properly operate and maintain the facilities once the intervention is completed.

It should be noted that the node “Capacity” represents one of the themes of the Water Poverty Index (WPI) developed by Sullivan (2002). Specifically, the aspect related to the capacity for sustaining access to water (Capacity, C_{WPI}).

Finally, a short description of each variable is presented in Table 13. In the same way, and in order to facilitate the understanding of the reader, the states considered for every node, as well as the source of information, are detailed.

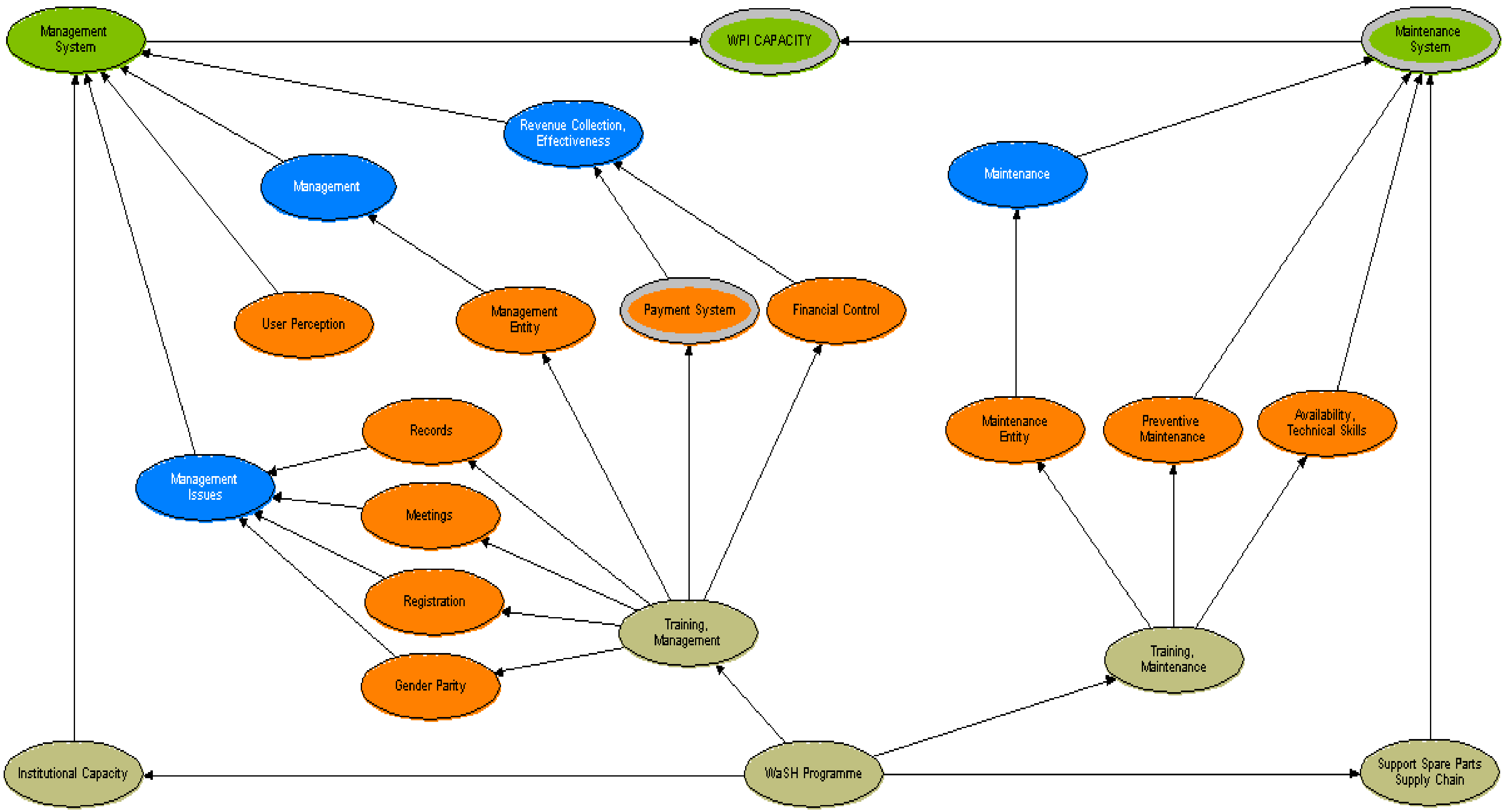


Figure 9. The Water Supply Capcity sub-nework.

Node	Description	States	Source
WaSH Programme	Training on financial management, accounting, supply management, reporting and M&E (monitoring and evaluation).	- 0: Current situation. - 1: Future situation (includes outputs after WaSH Programme implementation).	WaSH Programme
Institutional Capacity	Institutional framework able to assist communities with regard to the water-point management (i.e. monitoring and evaluation).	- Poor: Less than 1 person trained / 25 community groups (it is considered the ratio >1/15). - Acceptable: More than 1 person trained / 25 com. groups (it is considered the ratio 1/15). - Good: 1 person trained / 10 community groups (it is considered the ratio 1/5).	WP_E8 / WaSH Programme
Training, Management	Institutional support to local water entities. Management training for community groups and water service providers.	- 0: Community groups with no training in management issues. - 1: Community groups adequately trained in management issues.	WP_E9 / WaSH Programme
Gender Parity	Gender parity within water entities (minimum of 30% women representation in management committee). This node only takes into consideration improved water-points.	- 0: Gender inequity. - 1: Gender equity.	WP_E3
Registrations	Water entities legally registered. This node only takes into consideration improved water-points.	- 0: No registration. - 1: Legal Registration.	WP_E4
Meetings	Water entities that regularly meet. This node only takes into consideration improved water-points.	- 0: The water entity does not regularly meet. - 1: The water entity regularly meets.	WP_E5
Records	Water entities that keep records. This node only takes into consideration improved water-points.	- 0: The water entity does not keep records. - 1: The water entity keeps records.	WP_E6
Management Issues	Assessment of the capacities of water entities to properly manage the service, at water-point level. This node only takes into consideration improved water-points.	- % of water entities that are actively managing the water-point. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
User Perception	Management of the water-point (user perception). This node will be used as a correction factor for evaluating the management of the system.	- 0: Unsatisfied. - 1: Satisfied.	HH_G2
Management Entity	Management of water-point. This node only takes into consideration improved water-points.	- No management, WUA, Management Committee, Individual, Municipality, Government, Institution, Others.	WP_E2
Management	Management of water-point. This node only takes into consideration improved water-points.	- 0: The source is not managed by local entities. - 0.5: The source is managed by regional level entities (Municipality or Government). - 1: The source is managed at local level, generally by user entities (WUA, Management Committee, Individual or Institution).	WP_E2
Payment System	Water entities that have a payment system in place. This node only takes into consideration improved water-points.	- 0: Water entity with no payment system in place. - 1: Water entity with a payment system in place.	WP_F1
Financial Control	Water entities with a financial control system in place. This node only takes into consideration improved water-points.	- 0: Water entity with no financial control system in place. - 1: Water entity with a financial control system in place.	WP_F7
Revenue Collection, Effectiveness	Effectiveness of revenue collection. This node only takes into consideration improved water-points.	- Percentage (in intervals) of water entities that are collecting revenues effectively. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
Management System	Water Supply Service Management, at water-point level. User perception is used as a corrector factor when there is not satisfaction with the service management.	- Percentage (in intervals) of water-points which are properly managed. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula

Node	Description	States	Source
Training, Maintenance	Institutional support to local water entities. O & M training for community groups and water service providers. This node only takes into consideration improved water-points.	- 0: Community groups with no training in O&M. - 1: Community groups adequately trained in O&M.	WP_E9 / WaSH Programme
Maintenance Entity	Maintenance of water-point. This node only takes into consideration improved water-points.	- No maintenance, WUA, Management Committee, Individual, Municipality, Government, Institution, Others.	WP_E10
Maintenance	Maintenance of water-point, at local level. This node only takes into consideration improved water-points.	- 0: The source is not maintained at local level. - 1: The source is maintained at local level, generally by user entities.	WP_E10
Preventive Maintenance	Effectiveness of preventive maintenance programmes. This node only takes into consideration improved water-points.	- 0: No preventive maintenance. - 0.5: Some preventive maintenance, but not regularly. - 1: Regular programme of preventive maintenance.	WP_E15
Availability , Technical Skills	Availability of technical skills, at local level. This node only takes into consideration improved water-points.	- 0: Tech. skills are not available when needed. - 0.5: Tech. skills are available, but not for all repairs. - 1: Tech. skills are available for all repairs.	WP_E11
Spare Parts Supply Chain	Support to spare parts supply chain development, at district level.	- 0: Spare parts are not available when needed. - 0.5: Spare parts are available, but not for all repairs. - 1: Spare parts are available for all repairs.	WP_E13 / WaSH Programme
Maintenance System	Water Supply Service Maintenance.	- Percentage (in intervals) of water-points which are properly maintained. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
CAPACITY	Capacity in operation, management and maintenance of water-points.	- Percentage (in intervals) of water-points which are properly managed, operated and maintained. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula

Note: WP and HH refer to Water-Point and Household questionnaire, respectively (see Annexe II). All states are quantified in percentage and results are presented as a probability distribution.

Table 13. Description of the variables employed for the construction of "Water Supply Capacity" sub-network, including states assigned and source of information.

4.2.2. Water Supply

As it was mentioned previously, a major aim of the institutional reforms following the Kenya Water Act 2002 was to clearly separate roles among different institutions in order to minimize duplication and maximize efficiency. Nevertheless, the required capital investment for rural water supply falls short of needs and is highly fragmented, making it difficult to manage and report on. Aspects for sustaining and developing services are comparatively underdeveloped. The equity of resource allocation, particularly in rural water supply, can be significantly improved. Additionally, this sub-sector lacks of adequate management systems, finance and capacity to monitor, maintain, and expand services (African Ministers' Council on Water 2011).

Kenya's water supplies are fed by rainfall, which is highly spatially variable, ranging from less than 200 mm. a year in the northern arid and semi-arid lands to 1,800 mm. in the western region (see Table 1 and Figure 3). Rainfall is also erratic and varies greatly throughout the year. There are two distinct rainy seasons: the "long rains" come from March to May and the "short rains" from October to December (UNEP 2009). Rainfall variability will likely increase with climate change, straining the natural resource, in which are based Kenya's economy and its citizens' livelihoods (Survey of Kenya 2003, WRI and others 2007).

Population pressures and increased human activity in and around wetlands are transforming them for commercial uses including agriculture, salt-panning, and fish farming, among others, and they are being compromised by pollution from agricultural runoff, industries, and municipal effluents that renders their waters unhealthy for humans and livestock (UNEP 2009). Therefore, protection of water resources remains a major challenge because of its cross-cutting nature and the complexity of the causes, which are broadly categorised as point and non-point sources. A comprehensive water resources protection programme requires monitor and control of pollution from the origin with all stakeholders involved (WRMA of Kenya 2012). Monitoring identifies the pertinent parameters of the hydrological cycle, assess the water availability spatially and temporally and evaluate the present and future water demands against the available resource (NEMA of Kenya 2008).

Agriculture uses just over three-quarters of the surface water withdrawn for human uses while domestic and industrial withdrawals account for 17.2 and 3.7 per cent, respectively. At the same time as water availability has been decreasing and rainfall variability rises with climate change, demand for water has also been growing. Population pressures and the increased pace and scale of human activities in watersheds are straining water supplies. As well, declining and degraded water supplies have led to conflicts among different users, such as between pastoralists and farmers, upstream and downstream users, humans and wildlife, among others (UNEP 2009). Water for domestic use, health and food are fundamental and therefore at given thresholds are considered as social needs. In such cases, water use becomes a human right and therefore should be made available to all dependants (WRMA of Kenya 2012).

Finally, it should be highlighted that health benefits associated with better water quality are smaller than those obtained through improving accessibility of water, if this leads to an increase in the volume of water used for personal and domestic hygiene practices (Cairncross and Feachem 2005; Esrey et al. 1991; Huttly, Morris, and Pisani 1997). In particular, Cairncross and Feachem (2005) suggest that when water is available within 1 km. (or half-an-hour' return journey of the home), water use does not significantly increase when the distance (or time) is reduced, until it is less than 100 m. When a water-point can be provided within each house or yard, water use may increase dramatically from 10-30 l. to 30-100 l. / person-day. These findings show that programme managers should not expect significant health benefits associated with increased accessibility of water unless (i) traditional water sources are particularly far away, (ii) queuing is time-consuming, or (iii) where water can be supplied to each household (Cairncross and Feachem 2005).

In addition to this, economical accessibility goes hand-to-hand with the physical one. From a regulatory point of view, much remains to be done, as the institution in charge's (Water Services Regulatory Board, WASREB) mandate and capacity to enforce license provisions, issue regulations, and make tariff reviews and determinations is yet to be fully exercised (African Ministers' Council on Water 2011). This fact affects directly the tariff regimes at different scales. The lack of regulation increases the possibility to not protect those vulnerable sectors of the society unable to afford the cost of water.

The Water Supply sub-network

This network (Figure 10) aims to represent the rest of key variables that the Water Poverty Index (WPI), introduced by Sullivan (2002), comprises. Thus, it evaluates aspects related to physical availability of water (Resources, R_{WPI}), extent of access to water both physically and economically (Access, A_{WPI}) and the ways in which water is used for different purposes (Use, U_{WPI}).

As it was done with the previous network, its nodes are structured taking into account the interventions that might influence the state of key variables ("objective" nodes). At the same time, it should be noted the existence of instance nodes which affect directly few of the variables of the network.

Taking a look to the left-side of the network, it is assessed whether or not people have access to improved water supplies, and the use they are able to give to water. By improved, it is understood a drinking-water source that, by nature of its construction or through active intervention, is protected from outside contamination, in particular from contamination with faecal matter (WHO/UNICEF 2008).

On the one hand, and as a key measure of physical accessibility ("Access, Service" node), a set of variables are used to determine the reduction of time invested in securing water after the interventions carried out by the WaSH Programme. At the same time, it is evaluated the operational status of the water-points as a consequence of the maintaining performance of the water resource. Last but not least, the water-point service level is quantified as a key factor that guarantees accessibility. Finally, it should be mentioned that only improved water-points are taking into consideration, as they are a requirement to provide safe drinking water.

On the other hand, economical accessibility ("Access, Income" node) is assessed as it can be a big burden for the most vulnerable groups within the community. In case of unaffordable expenses, the poor might be forced to collect water from unprotected sources - when available - or to manage with minimum amounts at other times. However, no data was collected on water user fees, the economical accessibility is measured, i) taking into account user's perception regarding the cost of water (only when a payment system is in place), ii) carrying out an assessment of several socio-economic characteristics of the users (e.g.: principle livelihood, family assets, housing type, etc.), and iii) considering the existence of tariff exemptions for vulnerable groups.

In this network, the time need to fetch water appears as the key factor that influences the use that families give to water ("Use" node), classified as domestic (drinking, cooking, bathing and laundry) and non-domestic (livestock and gardening). This variable tries to highlight that water availability for non-domestic purposes is as important as domestic consumption.

Regarding the right-half of the network, it is measured the availability of water resources that do not present any sanitary risk ("Resources" node). It is based in the context of diminishing water availability with quality standards as a result of inadequate maintenance of water resources on the supply side, and increasing use of water related to population size and subjected to water-points seasonality.

In this respect, a set of variables determine water availability as a function of an evaluation regarding the possibility to use water for domestic and non-domestic purposes and the existence of conflicts emerged in this context (the amounts of water required for purposes other than domestic needs are often larger, and this can lead to competition between uses). As mentioned above, the seasonal resource variability is another factor that has been taken into account. However, lack of relevant data is a major constraint when these variables are assessed at local scale. Hydro-geological data are basically non-existent and groundwater recharges unknown. Information sources employed to assess these nodes have thus been qualitative.

Finally, a short description of each variable is presented in Table 14. The states considered for every node and the source of information are detailed as well.

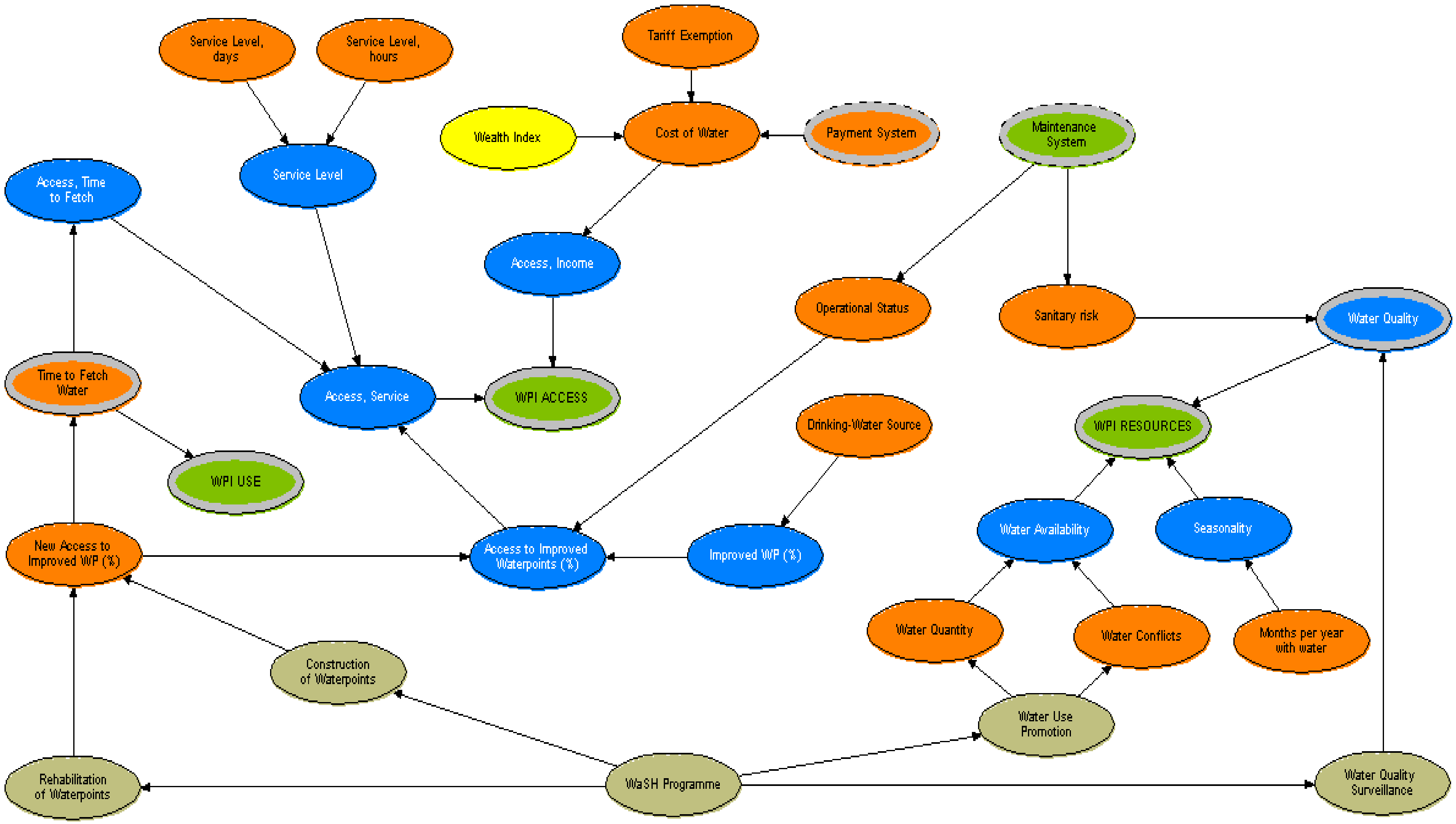


Figure 10. The Water Supply sub-network.

Node	Description	States	Source
WaSH Programme	Training on financial management, accounting, supply management, reporting and M&E (monitoring and evaluation).	- 0: Current situation. - 1: Future situation (includes outputs after WaSH Programme implementation).	WaSH Programme
Rehabilitation of Water-points	New beneficiaries accessing improved drinking-water sources because of rehabilitation of existing water-points.	- 0: No new beneficiaries of the WaSH Programme. - 1: New beneficiaries of the WaSH Programme.	WaSH Programme
Construction of Water-points	New beneficiaries accessing improved drinking-water sources because of new construction of WP.	- 0: No new beneficiaries of the WaSH Programme. - 1: New beneficiaries of the WaSH Programme.	WaSH Programme
New Access to Improved Water-points	New beneficiaries accessing improved drinking-water sources because of the WaSH Programme.	- Percentage (in intervals) of new beneficiaries of the WaSH Programme. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
Time to Fetch Water	Time spent in fetching water, in minutes (including queuing).	- All states are in minutes. (0 - 1, 1 - 10, 10 - 30, 30- 60, 60 - inf)	HH_D5 and HH_D7
USE	Use of water.	- 0: Only for drinking. - 0.5: For drinking and other domestic purposes. - 1: For domestic purposes and other non-domestic purposes.	Formula
Access, time to fetch	People with adequate access to water, in terms of time spent hauling water.	- 0: Time spent collecting water is not adequate. - 1: Time spent collecting water is adequate.	Expert opinion
Service Level, hours	Service level of the water supply (hours per day).	- All states (in intervals) are in hours per day. (0 - 6, 6 - 12, 12 - 18, 18 - 24)	WP_G7
Service Level, days	Service level of the water supply (days per week).	- All states (in intervals) are in days per week. (0 - 3, 4 - 5, 5 - 6, 7)	WP_G6
Service Level	Service level of the water supply.	- 0: Poor service level. - 0.5: Acceptable Service level. - 1: Good Service level.	Expert opinion
ACCESS, SERVICE	People who access to a reliable improved water-point.	- Percentage (in intervals) of people who access a reliable improved water-point. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
Maintenance System	Water Supply Service Maintenance.	- Percentage (in intervals) of water-points which are properly maintained. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Input node
Operational Status	Operational status of water-points, taking into account the maintenance provided. Data about functionality based on technology are considered to be homogeneous at national level.	- 0: "Not operational" (included "under rehabilitation"). - 1: "Operational".	WP_D1
Drinking - Water Source	Main source of drinking-water for members of the household for most part of the year.	- Piped into dwelling, Piped into yard or plot, Public tap/standpipe, Borehole, Protected dug well, Protected spring, Rainwater collection, Unprotected dug well, Unprotected spring, Tanker-truck, Cart with small tank / drum, Surface water.	HH_D1
Improved Water-points	People accessing improved drinking-water sources. Improved and unimproved technology, as defined in the JMP.	- 0: Unimproved technology, based on the JMP classification. - 1: Improved technology, based on the JMP classification.	HH_D1
Access to Improved Water-points	People accessing improved and functional drinking-water sources. Improved and unimproved technology, as defined in the JMP.	- Percentage (in intervals) people accessing improved and functioning water-points. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
Payment System	Water entities that have a payment system in place. This node only takes into consideration improved water-points.	- 0: Water entity with no payment system in place. - 1: Water entity with a payment system in place.	Input node

Node	Description	States	Source
Tariff exemption	Water entities subsidize the water supply services to vulnerable groups (poor household, HH headed by female, HH headed by child ...).	- False: No exemption from paying for water. - True: Existence of tariff exemption.	WP_F3
Wealth Index	Wealth index, based on assets. Groups are divided into quartiles.	- Poorest. - Poor. - Rich. - Richest.	HH_L
Cost of Water	Data on amount spent for water is unlikely to be reliable. As a proxy, it is used user perception of the amount spent on water.	- Cheap. - Fair. - Expensive.	HH_F8
ACCESS, INCOME	People who access water depending on income.	- 0: Some people cannot access to water all the time. - 1: All people can access to water all the time.	Expert opinion
ACCESS	People who access to water in terms of a reliable improved water-point and affordable price of the resource.	- Percentage (in intervals) of people who access to water in terms of a reliable improved water-point and affordable price of the resource. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
Water Use Promotion	Promotion of multiple use of water.	- False: No promotion of multiple use of water. - True: Promotion of multiple use of water.	WaSH Programme
Water Quantity	Water quantity sufficiency for multiple uses. User satisfaction is taking into account as a proxy.	- 0: Not sufficient even for domestic use. - 0.5: Only sufficient for domestic use. - 1: Always sufficient (for both domestic and other non-domestic uses).	WP_G1
Water Conflicts	Water conflicts around the water-point due to water availability, to water use efficiency and / or to different water uses.	- 0: Presence of conflicts. - 1: No presence of conflicts.	WP_G3
Water Availability	Water availability, at water-point level.	- Percentage (in intervals) of water-points with adequate water availability. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
Months per year with water	Months per year with water.	- All states (in intervals) are in months per year. (0 - 6, 6 - 8, 8 - 10, 10 - 11, 12)	WP_G5
Seasonality	Seasonality of water-points. A water point is considered year-round if it is not reported a seasonality of more than one month.	- 0: Seasonal water-point. - 1: Year-round water-point.	WP_G5
RESOURCES	Physical availability of water.	- Percentage (in intervals) of water-points providing water in a continuously and with quality. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
Water Quality Surveillance	Water quality surveillance and monitoring.	- 0: No water quality surveillance. - 1: Water quality surveillance.	WaSH Programme
Sanitary Risk	Likelihood of contamination occurring at the water-point.	- 0 - 0.5: High sanitary risk. - 0.5 - 0.75: Medium sanitary risk. - 0.75 - 1: Low sanitary risk.	WP_H
Water Quality	Water Quality, at water-point level. The indicator used comprises different data to assess the likelihood of sanitary risk.	- Percentage (in intervals) of water-points with adequate water quality. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula

Note: WP and HH refer to Water-Point and Household questionnaire, respectively (see Annexe II). All states are quantified in percentage and results are presented as a probability distribution.

Table 14. Description of the variables employed for the construction of "Water Supply" sub-network, including states assigned and source of information.

4.2.3. Hygiene

The fact that some diarrheal diseases are still prevalent in communities with a high level of water supply service indicates that water supply alone cannot completely prevent these diseases (Cairncross and Valdmanis 2006).

Lack of access to safe water and adequate sanitation are major underlying causes of several diseases, including diarrhoea, intestinal helminths, schistosomiasis, common eye infections such as trachoma, and skin diseases. However, water and sanitation improvements do not automatically produce the desired effects on population health. To ensure that health impacts materialize, the inclusion of hygiene education is required. Certainly, the reduction of water-related diseases depends on multiple improvements in home hygiene. In brief, of primary importance is the safe disposal of human faeces, thereby reducing the pathogen load in the ambient environment. Similarly, increasing the quantity of water allows for better hygiene practices, while raising the quality of drinking water reduces the ingestion of pathogens. Last but not least, an appropriate hygiene of the compound would decrease the contact and possible ingestion of pathogens as well. Therefore, if health benefits are to be realized, many other changes must be brought about in rural communities besides simply installing new hardware. At least, it involves changing hygiene habits, otherwise health indicators may not improve.

The Hygiene sub-network

This network (Figure 11) pursues the evaluation of the four different components of an aggregated index (Webb et al. 2006) that represent a different transmission route by which oral–faecal contamination may occur: drinking-water (DW_{HPI}), food (F_{HPI}), personal hygiene (PH_{HPI}); and domestic household hygiene (DH_{HPI}).

As previously mentioned, the nodes of this network are structured taking into account the interventions that might influence the state of key variables (“objective” nodes). At the same time, it is remarkable existence of instance nodes which affect directly few of the variables of the network.

Focusing on the central part of the network, it is evaluated the impact of hygiene-related educational interventions. This aspect was found critical in putting up barriers to the faecal-oral transmission of diseases. This is because, after adopting hygiene practices, beneficiaries choose safe water resources, ensure their families learn to wash their hands, wash their hands before preparation of food and before eating or feeding children (GoK and UNICEF 2006). Hygiene education also deals with measures as keeping animals out of the kitchen, cleaning the compound periodically and disposing correctly human faeces. At the same time, it is assumed that educational level plays a key role to ensure efficacy of hygiene promotion campaigns and it is assessed the influence of fetching water in household consumption rates.

A second set of nodes, located on the right side of the network, centres its attention specifically in hand-washing. Dealing with its promotion individually is sustained by studies supporting the effect of hand washing with soap, showing that this simple measure is associated with a reduction of 43 percent in diarrheal disease (Curtis and Cairncross 2003). These first two sets of nodes might reduce the burden of water-washed diseases, favoured by inadequate hygiene conditions and practices (Cairncross and Valdmanis 2006).

Finally, a third set of nodes indicates that water may become contaminated by poor collection, transportation and handling practices; as people collect it from a source in different sanitary risk conditions and take it home. Therefore, safe storage of drinking water might substantially decrease the burden of water-borne diseases. On the other hand, there is considerable debate about the impact of household water treatment on diarrhoea (Cairncross and Valdmanis 2006; Fewtrell et al. 2005), so its promotion as an effective practise appears to be premature.

Finally, a short description of each variable is presented in Table 15. As previously done, the states considered for every node and the source of information are detailed as well.

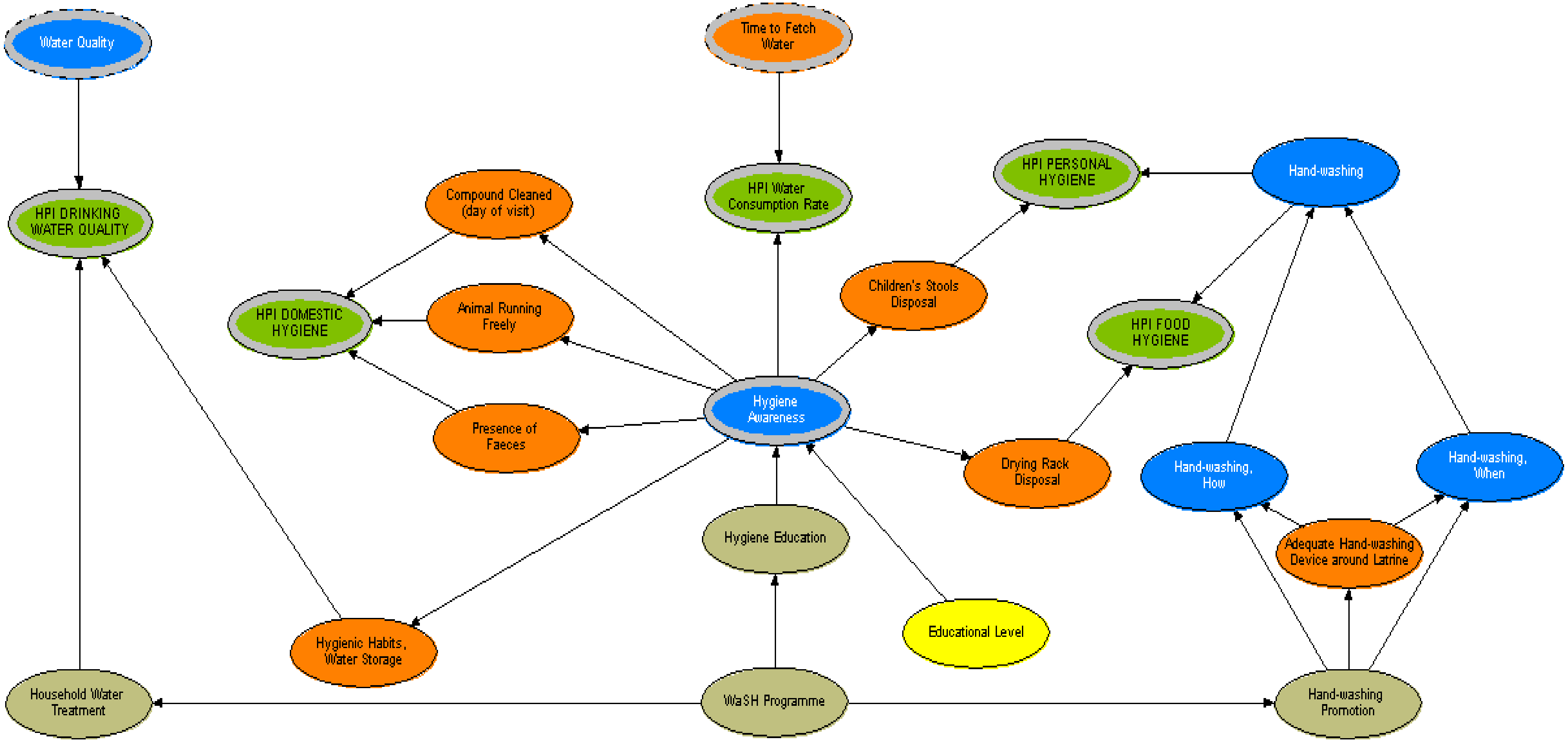


Figure 11. The "Hygiene" sub-network.

Node	Description	States	Source
WaSH Programme	Promotion to practice appropriate hygiene practices especially hand washing with soap (or ash) at key occasions and promotion to practice point of use water treatment, safe water storage and hygienic handling of water.	- 0: Current situation. - 1: Future situation (includes outputs after WASH Programme implementation).	WaSH Programme
Hygiene Education	Hygiene education to households, through direct and mass marketing.	- 0: Households that do not receive hygiene education. - 1: Households that receive hygiene education.	WaSH Programme
Educational Level	Educational level, based on a proxy of households head literacy (% of household heads with primary completed).	- 0: Household head is illiterate (primary not completed). - 1: Household head is literate (primary completed).	HH_C4
Hygiene Awareness	Health knowledge and hygiene awareness within the community members. It assumes that educational level plays a key role to ensure efficacy of hygiene promotion campaigns.	- Percentage (in intervals) of households with adequate hygiene behaviour. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
Compound Cleaned (day of visit)	Compound swept on day of visit.	- 0: Compound NO swept on day of visit. - 1: Compound swept on day of visit.	HH_I5
Animals Running Freely	Animals running around freely in the compound.	- 0: Animals running freely around in the compound. - 1: NO Animals running freely around in the compound.	HH_I5
Presence of Faeces	Presence of human/animal faeces in the compound.	- 0: Presence of human/animal faeces in the compound. - 1: NO Presence of human/animal faeces in the compound.	HH_I5
DOMESTIC HYGIENE	Assessment of domestic hygiene due to different variables.	- Percentage (in intervals) of households with appropriate hygiene conditions. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
Hygienic Habits, Water Storage	Hygienic habits, at household level. It assesses adequacy of water storage to prevent contamination as a proxy of hygienic habits within the household members.	- 0: Stored water with risk of contamination (less than 5 positive answers). - 1: Stored water with NO risk of contamination (5 to 6 positive answers).	HH_E7
Children's Stools Disposal	This node assesses percentage of caregivers correctly handling baby excreta. This indicator is promoted by the JMP, which defines proper handling of children's stools when household environment is protected from faecal contamination; i.e. (i) faeces are buried, (ii) faeces are disposed into a toilet or latrine; or (iii) the child uses the toilet or latrine.	- 0: Caregivers do not handle baby excreta correctly. - 1: Caregivers correctly handle baby excreta.	HH_I3
Drying Rack Disposal	Households with a drying rack for plates and cups.	- 0: NO possession of drying rack disposal. - 1: Possession of drying rack disposal.	HH_I4
Household Water Treatment	Assessment of point-of-use water treatment. This node is calculated as the percentage of households which are in the habit of adequately treat water (e.g. boiling) previous consumption. Adequacy of point-of-use treatments is defined by the JMP.	- 0: Households with no point-of-use water treatment. - 1: Households with point-of-use water treatment.	HH_E9 / WaSH Programme
DRINKING WATER QUALITY	Water Quality for domestic purposes, at household level. This node aims to calculate the percentage of households that drink safe water.	- Percentage (in intervals) of households with safe water for drinking. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - inf)	Formula
Water Quality	Water Quality, at water-point level. The indicator used comprises different data to assess the likelihood of sanitary risk.	% of waterpoints with adequate water quality. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - inf)	Input node
Time to Fetch Water	Time spent in fetching water, in minutes.	- All states (in intervals) are in minutes. (0 - 1, 1 - 10, 10 - 30, 30- 60, 60 - inf)	Input node

Node	Description	States	Source
DOMESTIC WATER CONSUM., DRINKING	Domestic water consumption rate, in litres per day per capita (l/d).	All states (in intervals) are in litres per day per capita (l/d). (0 - 20, 20 - 50, 50 - 100, 100 - inf)	HH_D17
Hand-washing Promotion	Hand-washing promotion through direct marketing. Hand-washing behaviour is taken as a proxy of personal hygiene. This node focuses on child caregivers, as core actor at household level. It assesses hand-washing behaviour.	- 0: Child caregivers who do not wash their hands. - 1: Child caregivers who do wash their hands after the training received.	HH_I1 / WaSH Programme
Adequate Hand-washing Device around Latrine	Households with an adequate hand-washing device around the latrine. "Adequate" refers to water and soap.	- 0: No adequate hand-washing device around latrine. - 1: Adequate hand-washing device around latrine.	HH_H7
Hand-washing, How	Adequate method for hand-washing. Proper hand-washing meets following criteria: (i) uses water, (ii) uses soap or ash, (iii) washes both hands, (iv) rubs hands together at least three times, and (v) dries hands hygienically, i.e. by air drying or using a clean cloth.	- Percentage (in intervals) of caregivers who wash their hands correctly. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
Hand-washing, When	Critical times for hand-washing. Critical times are defined as (i) after defecation, (ii) after cleaning babies' bottoms, (iii) before food preparation, (iv) before eating, and (v) before feeding children.	- Percentage (in intervals) of caregivers who wash their hands at critical moments. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
Hand-washing	This node assesses adequacy of hand-washing, in terms of method and frequency.	- Percentage (in intervals) of caregivers that wash their hands correctly and at critical moments. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
FOOD HYGIENE	This node assesses adequacy of food hygiene, in terms of hygienic conditions at feeding time.	- Percentage (in intervals) of caregivers who proportionate hygienic conditions at feeding time. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
PERSONAL HYGIENE	Personal hygiene within the household members, considering caregivers as a proxy.	- Percentage (in intervals) of caregivers with adequate personal hygiene. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula

Note: WP and HH refer to Water-Point and Household questionnaire, respectively (see Annexe II). All states are quantified in percentage and results are presented as a probability distribution.

Table 15. Description of the variables employed for the construction of "Hygiene" sub-network, including states assigned and source of information.

4.2.4.Sanitation

The service delivery pathway for rural sanitation is less developed than either water supply sub-sectors, in particular for developing services. Among policy issues, public support for sanitation hardware (i.e. latrines, septic tanks, wastewater systems, etc.) vs. software (i.e. training, capacity building, demand promotion, supply promotion, monitoring, etc.) must be clarified. Although Kenya has a National Environmental Sanitation and Hygiene Policy, it is not clear on how households are to be encouraged to invest in sanitation, and how this will be financed (African Ministers' Council on Water 2011).

The constraint most frequently mentioned by unserved householders is cost, but this factor is usually more a perceived constraint than an objective one. Other constraints include lack of ready access to necessary techniques and skills or to specific building materials and components (Cairncross and Valdmanis 2006).

There are important externalities to households' investment in sanitation. Households are protected from their own faeces by their sanitation facilities, but so, too, are their neighbours, and this factor is probably more important in epidemiological terms. If households are not fully aware of the health benefit, or if much of it accrues to others, a case exists for public intervention to increase coverage because these externalities exist (Cairncross and Valdmanis 2006).

As it was highlighted previously, capacity building and development of a reliable supply chain needs to be supported to ensure sector skills and spare parts availability. Promotion of improved hygiene practices, including appropriate use and maintenance of the sanitation facilities, is another possible intervention to carry out. All of those measures will help increase sanitation coverage and health benefits and are appropriate interventions for the health sector (Cairncross and Valdmanis 2006).

The sanitation sub-network

This network (Figure 12) aims to represent all key variables that determine whether or not people have access to improved sanitation, use it constantly under hygienic conditions and are able to contract and repair the facility. Thus, its structure is ordered according to the interventions that might influence the state of key variables ("Objective" nodes).

A first set of nodes (half-left of the network) deals with the extent of access to sanitation, both in terms of accessibility and affordability. This is, a facility accessible within or in the immediate vicinity of each household, and available at a price that everyone could afford it. At the same time, this set of nodes focuses on improved sanitation which is based in two parameters. On the one hand, and regarding the sanitation technology, it is distinguished between improved and unimproved latrines (WHO/UNICEF 2008). On the other hand, sanitation technologies are considered as providing adequate access to sanitation as long as they are private (but not shared / public) and hygienically separate human faeces from human contact (WHO/UNICEF 2010). As access to basic services is strongly linked to social and economic conditions, the impacts of inadequate sanitation are felt most acutely by vulnerable groups. Thus, access in terms of affordability is evaluated carrying out an assessment of several socio-economic characteristics of the users (e.g.: principle livelihood, family assets, housing type, etc.).

A second set of nodes (right side of the network) determines the conditions of the latrine, since a facility that it is not well-maintained might become a focus for transmission of diseases. In addition, a toilet maintained correctly offers a pleasant environment in which to urinate or defecate, and this might act as a motivation factor to use the facility (Scott, Cotton, and Govindan 2003). These conditions are evaluated using four proxy indicators which are associated with hygiene outcomes (privacy, cleanliness, smell and presence of insects), and therefore they are assumed to be affected by hygienic awareness among the population.

Finally, a third set of nodes (centre-bottom of the network) assesses people's capability to construct and repair the latrine, in terms of availability of technical skills and materials respectively. It should be reminded that the consistent use of the facility, not its mere existence, is which leads to health and environmental improvements (Giné Garriga et al. 2011).

Finally, a short description of each variable is presented in Table 16. As previously done, the states considered for every node and the source of information are detailed as well.

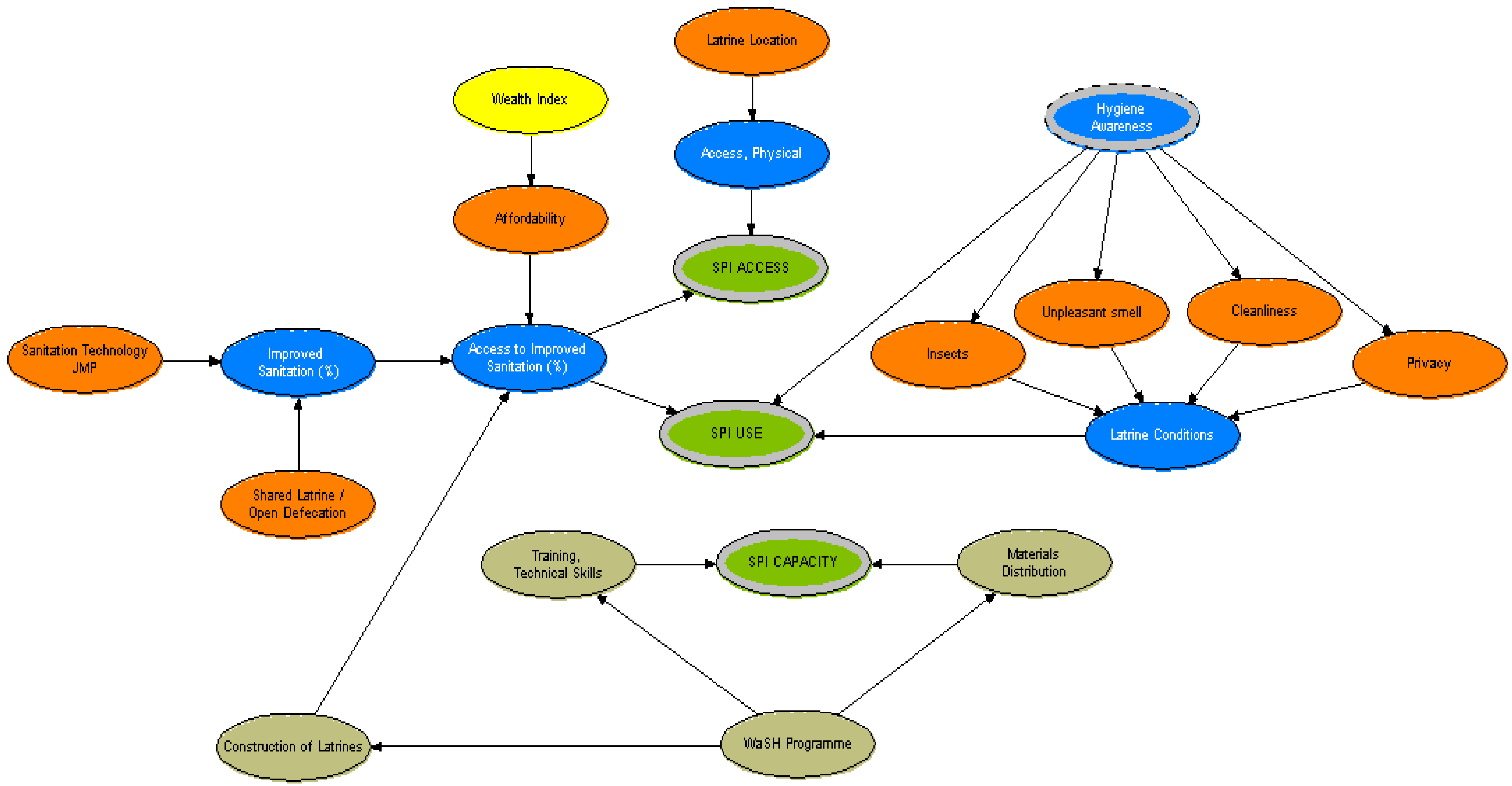


Figure 12. The SAnitation sub-network.

Node	Description	States	Source
WaSH Programme	Construction of hygienic toilet facilities with hand-washing facilities at household level, distribution of materials by implementation of local component production units and training of community sanitation promoters in construction of sanitation facilities.	- 0: Current situation. - 1: Future situation (includes outputs after WaSH Programme implementation).	WaSH Programme
Construction of Latrines	New beneficiaries accessing improved sanitation facilities because of new construction of toilets.	- 0: No new beneficiaries accessing improved sanitation facilities. - 1: New beneficiaries accessing improved sanitation facilities because of new construction of toilets.	WaSH Programme
Sanitation Technology	Type of sanitation facility the household has. Classification according to the criteria of the Joint Monitoring Programme of WHO/UNICEF (2008)	- 0: Unimproved sanitation technology (Poor flush to unknown place, Pit latrine without slab / Open pit, Bucket, Hanging Latrine). - 1: Improved sanitation technology (Flush to a septic tank, Flush to pit (latrine), Ventilated Improved Pit latrine (VIP), Pit latrine with slab).	HH_H1.1
Shared Latrine / Open Defecation	Households whose members share the sanitation facility that is currently being used or practise open defecation.	- 0: No facility, bush or field (OPEN DEFECATION) - 0.5: Yes, it is a shared facility. - 1: No, the facility is for this household only.	HH_H15
Improved Sanitation	Households accessing improved sanitation.	- Percentage (in intervals) of households accessing improved sanitation. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
Wealth Index	Wealth index, based on assets. Groups are divided into quartiles.	- Poorest. - Poor. - Rich. - Richest.	HH_L
Affordability	Households with no latrine because of a lack of economic resources (affordability issues).	- Percentage (in intervals) of households with no latrine because of a lack of economic resource. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
ACCESS TO IMPROVED SANITATION	Households accessing improved sanitation.	- Percentage (in intervals) of households accessing improved sanitation due to the existence of the facility and economical resources. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
Training, Technical Skills	Training of community sanitation promoters in construction of sanitation facilities.	- Number (in intervals) of community sanitation promoters per 1000 households. (0 - 2, 2 - 4, 4 - inf)	WaSH Programme / HH_H13 (B and D)
Materials Distribution	Distribution of materials by implementation of local component production units.	Number (in intervals) of local component production units per 1000 households. (0 - 1, 1 - 3, 3 - inf)	WaSH Programme / HH_H13 (C and D)
CAPACITY	Maintenance and repair of latrines.	- 0 - 0.25: No access to skills and materials for repairing the latrine. - 0.25 - 0.50: Poor access to skills and materials. - 0.50 - 0.75: Good access to skills and materials. - 0.75 - 1: Excellent access to skills and materials.	Formula
Hygiene Awareness	Health knowledge and hygiene awareness within the community members. It assumes that educational level plays a key role to ensure efficacy of hygiene promotion campaigns.	- Percentage (in intervals) of households with adequate hygiene behaviour. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Input node
Insects	Presence of insects.	- 0: Presence of a lot of insects. - 0.5: Presence of few insects. - 1: No presence of insects.	HH_H8
Unpleasant smell	Presence of unpleasant smell.	- 0: Presence of a strong unpleasant smell. - 0.5: Presence of a slight unpleasant smell. - 1: No smell.	HH_H9

Node	Description	States	Source
Privacy	Privacy conditions of the facility.	- 0: No privacy. - 0.5: Poor privacy. - 1: Adequate privacy.	HH_H10
Cleanliness	Cleanliness conditions of the latrines.	- 0: No clean. - 0.5: Poorly clean. - 1: Adequately clean.	HH_H11
Latrine Conditions	Latrine conditions regarding the separation of excreta from human contact, the privacy conditions, presence of insects, smell and cleanliness.	- 0 - 0.25: Latrine in risky conditions. - 0.25 - 0.50: Latrine in poor conditions. - 0.50 - 0.75: Latrine in acceptable conditions. - 0.75 - 1: Latrine in excellent conditions.	Formula
USE	Households using improved sanitation.	- Percentage (in intervals) of households using improved sanitation. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula
Latrine Location	Location of the latrine	- Outside the compound - Inside the compound - Inside the house	HH_H3
ACCESS, PHYSICAL	Household accessing a toilet in the same house or compound.	0: Outside the interviewed compound. 0.5: At the interviewd compound 1: At the interviewed house.	Expert opinion
ACCESS	Households accessing improved, affordable and physically accessible sanitation.	- Percentage (in intervals) of households accessing improved, affordable and physically accessible sanitation. (0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, 0.75 - 1)	Formula

Note: WP and HH refer to Water-Point and Household questionnaire, respectively (see Annexe II). All states are quantified in percentage and results are presented as a probability distribution.

Table 16. Description of the variables employed for the construction of "Sanitation" sub-network, including states assigned and source of information.

4.2.5. Water, Sanitation and Hygiene Poverty Index (WaSH-PI)

As constantly mentioned, in order to represent theoretical framework of the WaSH Poverty Index, an ooBn approach has been used, exploiting the flexibility of Bns.

In this respect, in previous sections each variable of the three composites were presented in a separate sub-network. In these four sub-networks, the "Objective" variables appear as output nodes, but also as input nodes in three additional sub-networks, which were developed to integrate each composite's component (see Figure 13).

A parenthesis should be done at this point regarding the three additional sub-networks. Firstly, it should be highlighted that the aggregation function employed was the geometric one of the equally weighted "Objective" nodes (see Annexe I). Additional nodes were created just to reduce time computing. As pointed in section 4.1.3, links between variables are not restricted to probability tables, and they can also be specified through a standard mathematical expression. This aggregation method was considered adequate as it doesn't allow a total compensation among nodes. In this way, if any of these "Objective" nodes was equal to zero, then the result of the aggregation would be zero as well. Secondly, these additional sub-networks were created in order to provide an easier visualization of the composites.

At the same time, it is worthy to remind the rationale of these three composites:

i) The Water Poverty Index is assessed considering physical availability of water (Resources, R_{WPI}), extent of access to water (Access, A_{WPI}), capacity for sustaining access (Capacity, C_{WPI}) and ways in which water is used for different purposes (Use, U_{WPI});

ii) The Sanitation Poverty Index, which not only gauges the extent of access to sanitation, both in terms of accessibility and affordability (Access, A_{SPI}), but assesses people's ability to construct and repair the latrine (Capacity, C_{SPI}), and includes those hygienic factors that enable a continued usage of the facility (Use, U_{SPI});

iii) The Hygiene Poverty Index, which considers that different transmission route by which oral–faecal contamination may occur: drinking-water (DW_{HPI}), food (F_{HPI}), personal hygiene (PH_{HPI}); and domestic household hygiene (DH_{HPI}). It should be noted that two other variables are added to the index, i.e.: water consumption rate and use of water. This fact pursued a more accurate definition of the reality and a demonstration of the potentiality of ooBn by linking nodes and sub-networks.

The Master Network

As mentioned, there are in total seven sub-networks that are linked together by using output and input nodes. These "instance" nodes thus enable the link between the sub-networks and the master network. At the same time, it is admitted that the simple causal relations are not appropriate to a good understanding of the overall system. It is believed that some variables are relevant for multiple sub-networks, and to accommodate them in one single network leads to oversimplification and fails to capture the crosscutting nature of water poverty issues. These variables are represented as interface nodes in more than one sub-network, as shown in Figure 14.

It can be seen from the master network visualization that any hypothetical change in a variable of any sub-network will result in a chain reaction of impacts on all linked variables, affecting the outputs of the overall system. In consequence, a major advantage of this tool is that it can easily infer the impact of a number of potential interventions on all interrelated factors. Based in such potentiality, identifying which action, or combination of actions, would generate desired results appears straightforward.

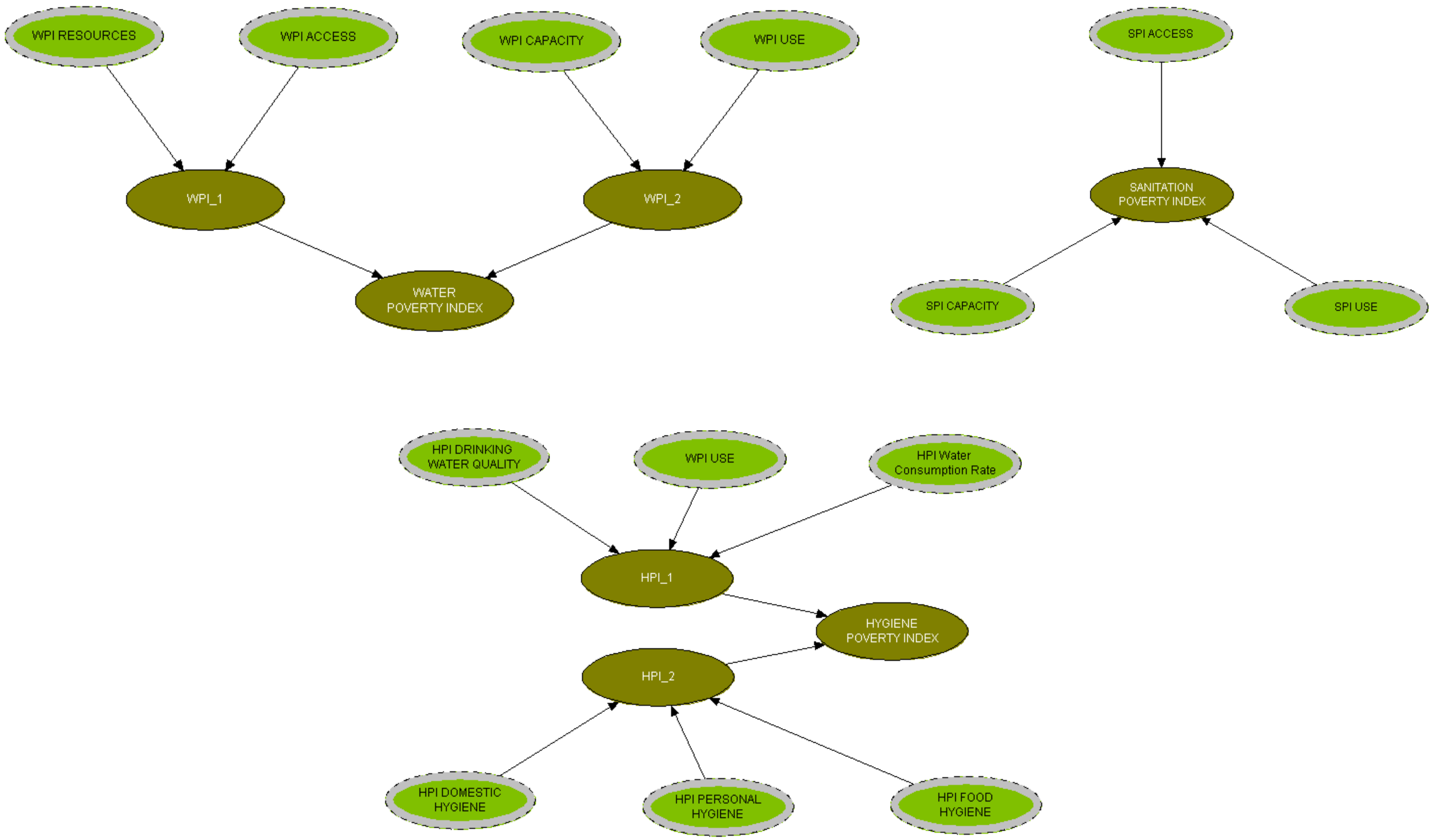


Figure 13. Representation of the three composites of WaSH-PI. Input nodes are ellipses with shadow dashed line borders. Intermediate nodes were created to reduce time-computing.

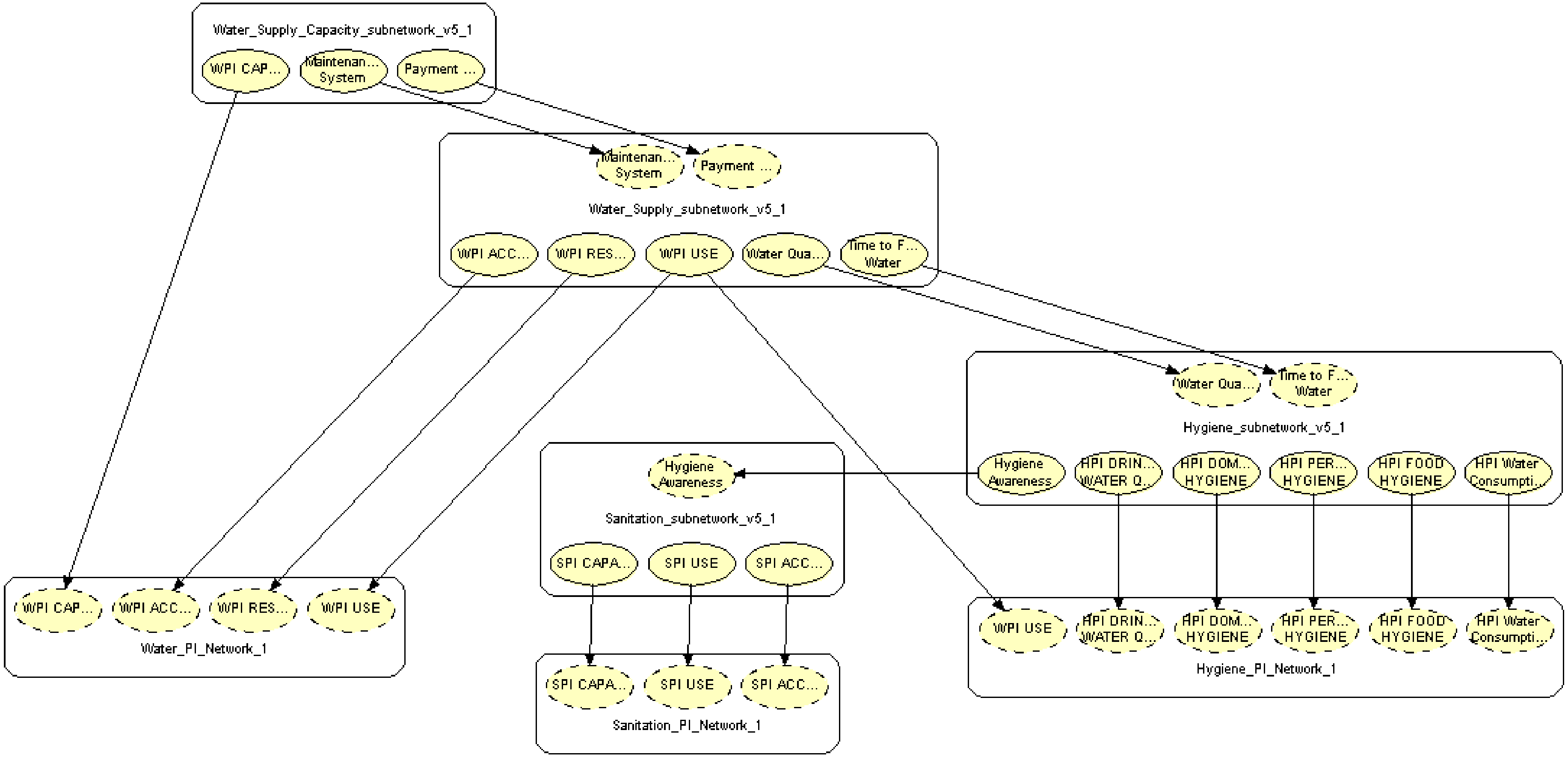


Figure 14. Scheme of the ooBn master network.

5. Results and Discussion

In this section, the results obtained by developing and using object-oriented Bayesian networks, as well as a further discussion, are presented.

Firstly, a comparison of the results, regarding the WaSH situation at national scale, is provided taking into account two different methodologies (i.e. ooBn and indexes). Secondly, an assessment of the WaSH Programme impact, at both intervened area and district level, is presented. Finally, it is explored other potential uses of this tool.

5.1. Bayesian networks vs. Indexes and indicators

This master thesis represents a first attempt of the development and application of an ooBn to assess water, sanitation and hygiene issues from an integrated approach.

As mentioned, the WaSH Poverty Index was selected as a suitable framework which integrates the key issues of the water and sanitation sector through an inter-disciplinary and WaSH-focused approach.

Taking into account that both ooBn and WaSH-PI employ common data, similar utility functions to normalize the information and same structure for assessing sectoral situation, a first exercise of comparing their results was carried out. Furthermore, main differences between these methodologies were assessed.

Table 17 and Figure 15 show the results provided by both methodologies. It can be noted that, even if the results of "Objective" variables (components of the three composites) present a heterogeneous degree of difference, the overall result regarding the three indexes present a similar tendency.

In addition to this, it should be highlighted that the WaSH-PI shows the mean and standard deviation of the intervened districts, while the ooBn presents the overall mean and standard deviation. Regarding this fact, the remarkable difference among the values of the standard deviations is explained.

WaSH Poverty Index

	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	A	C	U	**WPI**	A	C	U	**SPI**	DW	PH	F	DH	**HPI**
Mean	0.66	0.25	0.21	0.66	**0.43**	0.44	0.72	0.40	**0.50**	0.64	0.36	0.40	0.53	**0.48**
Std Dev	0.09	0.09	0.09	0.06	**0.07**	0.19	0.14	0.17	**0.14**	0.15	0.06	0.17	0.09	**0.08**

Object-oriented Bayesian networks

	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	A	C	U	**WPI**	A	C	U	**SPI**	DW	PH	F	DH	**HPI**
Mean	0.56	0.47	0.49	0.66	**0.48**	0.39	0.71	0.45	**0.47**	0.50	0.31	0.34	0.52	**0.46**
Std Dev	0.14	0.22	0.14	0.24	**0.14**	0.14	0.10	0.14	**0.14**	0.17	0.20	0.26	0.20	**0.17**

Table 17. Comparison among results provided by the WaSH-PI and ooBn before WaSH Programme implementation.

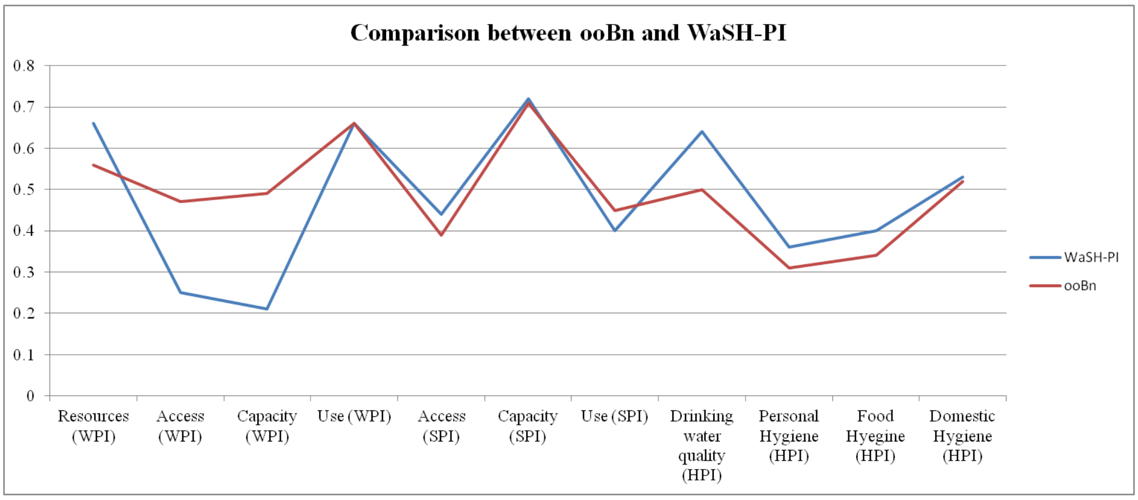


Figure 15. Graphical comparison among results provided by WaSH-PI and ooBn, regarding the three composites' key variables ("Objective" nodes).

More remarkable differences can be found on those variables regarding access to water (A_{WPI}) and water point management capacity (C_{WPI}). There exists a specific reason for this, which falls on the data employed for evaluating these aspects. In the case of the ooBn, "Capacity" variable is constructed from the quantitative information available on the "Water-point questionnaire" (see Annexe II), while the WaSH-PI processes the data related to similar aspects from the "Household questionnaire" (see Annexe II). At the same time, the former gets details from the entity that manages and maintains the WP (i.e. water user association, management committee, government, municipality, etc.), the latter extracts information from the participation of households in management and maintenance issues. On the other hand, the differences related to "Access" variable fall on the underneath variables, even though both OoBn and WaSH-Pi employ the same surveys. In the case of the ooBn, a higher amount of interlinked variables are taken into consideration to evaluate this aspect.

Such discrepancies are not so remarkable in the other nodes and sub-networks, as similar variables (in terms of nature and quantity) were considered. It should be reminded that it is not pursued a detailed comparison of each variable between both methodologies. The most important observation is that, regarding sectoral decision making, these methods identify equally those aspects that require a priority intervention. In this way, this comparison might perform as a validation process, concluding that ooBn accommodates appropriately the situation of WaSH-related issues.

At this point, it is also considered to point out the main differences detected in both results achieved and methodology. This is important to mention in order to correctly interpret following sections.

A first remarkable observation falls on how results are presented. ooBn provides directly a result in form of probability distributions (CPTs) while indexes and indicators normally are expressed by central estimates, although these can be expressed as probability distributions as well. From a distribution, there is also the possibility to extract a mean and its variance or standard deviation. Nevertheless, a same mean value might be obtained by different probability distributions. In this way, ooBn offers the chance to introduce this possibility into the assessment.

Another advantage, regarding results presentation, is specifically displayed by the use of ooBn, which provides with the possibility to observe impacts in other dimensions related indirectly through the networks.

As far as results visualization, it is considered that Bns offers a more straightforward way for further interpretation. On the one hand, this tool reflects the way in how human-beings conceptualize the reality. On the other hand, this DSS provides a holistic and transparent framework on which causal-effect decisions in WaSH planning and management can be based.

Regarding this last aspect, both methodologies might be used for sectoral planning. They allow establishing priorities, at the same time that permit to assess the impact of different interventions. However, this last process is not extended when using indexes and indicators. What makes a difference to this regard is the potentiality of doing this process backwards. This is, fixing a desired value of a variable in order to obtain the interventions required to achieve the expected result.

The objective of detailing these observations was to introduce, to some extent, the next sections and to justify the processes carried out.

5.2. Assessment of the WaSH Programme impact at total intervened area scale

The task of evaluating the overall impact of a WaSH Programme is a complex and daunting task. It goes beyond simply assessing a defined set of verifiable indicators or determining an objective number of beneficiaries. This involves the integration of a large number of variables, which are in turn marked by some degree of uncertainty. It thus requires a transparent means of representing the produced effects of different project approaches while dealing with different uncertainty sources that inevitably exists with development interventions in the water sector. As mentioned, an ooBn approach was adopted for this purpose.

To this end, two different scenarios were simulated. On the one hand, the first scenario was assumed to be described by the current situation, where no intervention had been carried out. On the other hand, the second scenario adopted the project approach. According to the Programme strategy, the set of actions to be implemented were represented in the networks as "Intervention" nodes (listed in Table 2 to 5). It is by acting on these variables that the software simulated both scenarios (see section 4.1.3 and Annexe I).

Sub-network	Variable	States	No Intervention	WaSH Programme
Water Supply Capacity	Institutional Capacity	The service is not being monitored by local authority	0.55	0.35
		The service is monitored and supported by local authority, but not regularly	0.45	0.5
		The service is adequately monitored and supported by local authority	0	0.15
	Training in Management	Community groups with no training in management issues	0.79	0.65
		Community groups adequately trained in management issues	0.21	0.35

	Training in Maintenance	Community groups with no training in O&M	0.82	0.68
		Community groups adequately trained in O&M	0.18	0.32
	Support in Supplying Spare Parts	Spare parts are not available when needed	0.28	0.14
		Spare parts are available, but not for all repairs	0.17	0.24
		Spare parts are available for all repairs	0.55	0.62
Water Supply	Rehabilitation of Water-points	No new beneficiaries accessing improved drinking-water sources	1	0.96
		New beneficiaries accessing improved drinking-water sources	0	0.04
	Construction of Water-points	No new beneficiaries accessing improved drinking-water sources	1	0.82
		New beneficiaries accessing improved drinking-water sources	0	0.18
	Water Use Promotion	No promotion of multiple use of water	1	0.25
		Promotion of multiple use of water	0	0.75
	Water Quality Surveillance	No water quality surveillance	1	0.25
		Water quality surveillance	0	0.75
Hygiene	Hygiene Education	Households that have not received hygiene education	0.87	0.68
		Households that have received hygiene education	0.13	0.32
	Hand-washing Promotion	Households that have not received hygiene education (hand-washing)	0.87	0.68
		Households that have received hygiene education (hand-washing)	0.13	0.32
	Household water treatment	Households not practising point-of-use water treatment	0.53	0.34
		Households not practising point-of-use water treatment	0.47	0.66
Sanitation	Construction of latrines	No new beneficiaries accessing to improved sanitation facilities	1	0.78
		New beneficiaries accessing to improved sanitation facilities	0	0.22
	Training in technical skills	No access to skills for latrine reparation	0.48	0.40
		Poor access to skills for latrine reparation	0.52	0.25
		Adequate access to skills for latrine reparation	0	0.35
	Materials Distribution	No access to materials for latrine reparation	0.59	0.45
		Poor access to materials for latrine reparation	0.41	0.40
		Adequate access to materials for latrine reparation	0	0.15

Table 18. Conditional Probability Tables of the “Intervention” nodes in two simulated scenarios at intervened area level.

The impacts of the WaSH initiative were inferred and compared with respect to the current situation, and such changes are presented in Figures 16, 17 and 18. In accordance with these graphs, the intervention would produce a positive impact on overall WaSH Poverty Index. However, this result is translated into a modest improvement after project completion. Nevertheless, the three composites provide a starting point for analysis. An accurate focus on the different variables might help to direct attention to those water and sanitation sector needs that require special policy attention.

For example, and in accordance with Figures 16 and 17, aspects requiring urgent intervention are those related to "Access" and "Capacity" to water supply and "Access" and "Use" to sanitation. At the same time, and even if hygiene related issues present the most remarkable improvements, aspects related to personal and food hygiene habits remain as the lowest values (see Figure 18).

An overall analysis shows that the Programme primarily impacts on the "Water Supply" and "Hygiene" sub-networks, while also improving, to different extent, the rest of variables. Specifically, the "Drinking Water Quality" objective variable experiments the highest improvement, which is closely linked to a similar increase of the "Resources" component.

On the other hand, the "Use" component, regarding water-related issues, decreases slightly. This paradigmatic case, which depends directly on the time spent in fetching water, is explained according to the existing evidences. This is, experience shows that a higher percentage of people, who uses water for only domestic purposes, exists when the time to haul water is reduced. Therefore, the simulation will increase this state of the variable against what it would be expected (less time to fetch water derives in more quantity of water and, consequently the probability to use for non-domestic purposes increases).

A more detailed description of achieved results at sub-network level is presented in following lines.

5.2.1. Water Supply Capacity

Capacity to manage water facilities is required both at local and regional scale, and a major challenge is thus to improve the capacity of the new institutions to perform as expected and lead in revitalising the water sector. Management challenges which are common to all water supply points are resource mobilisation for development and maintenance, operations, revenue collection and accountability and group dynamics which include the question of the participation of women.

The project will help the new sector-related organizations to meet the necessary skills and abilities to assume their commitment. In particular, the capacity building process includes the provision of basic equipment and training in planning, procurement and management skills. At community level, women groups will receive priority in the ownership of the water facilities and in the process of hygiene and sanitation promotion.

Equally important, stimulation and strengthening of the local private sector for the development of adequate spare parts supply chain will be supported. By procuring materials locally where suitable and by using local artisans and masons for low-cost and simple construction works, it will be provided an additional economic benefit to the private sector in the project areas.

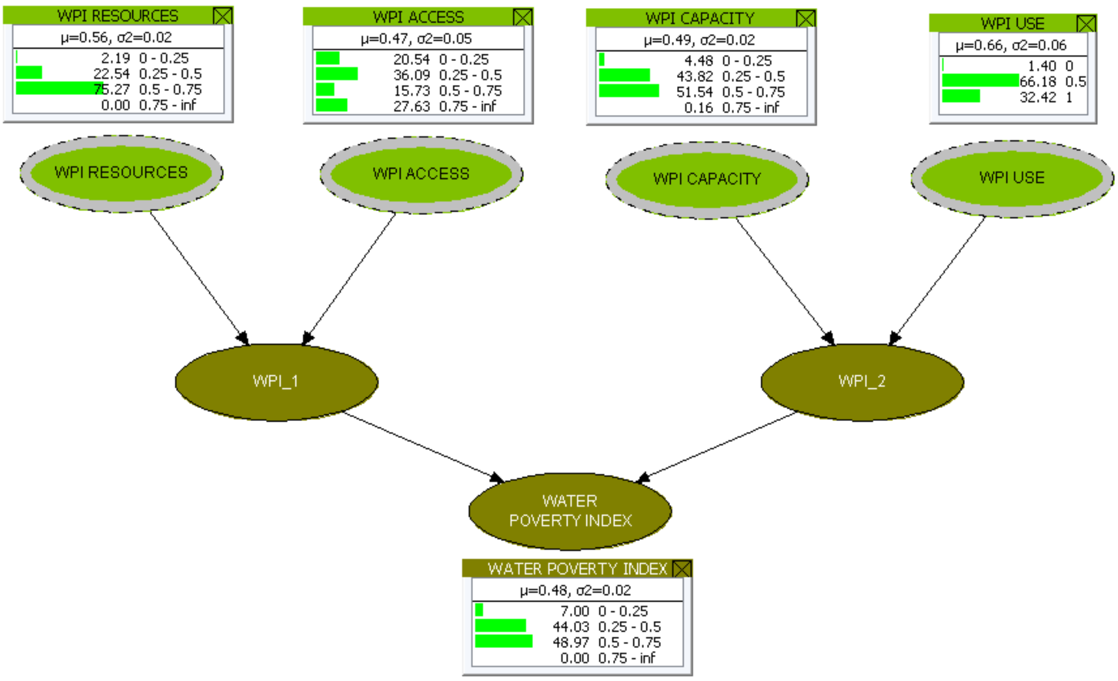
An exhaustive analysis of the results obtained permits to conclude that the institutional framework to support communities to manage water facilities is far from adequate. In the same way, the role of women is unlikely to experiment a remarkable improvement. It must be noted that these results are a consequence of the existing evidences before Programme implementation. Taking into account the project approach, especially care should be given to these aspects. In this way, a mid-term monitoring shows up to be essential to both calibrate the networks and re-think the intervention strategy if needed.

5.2.2. Water Supply

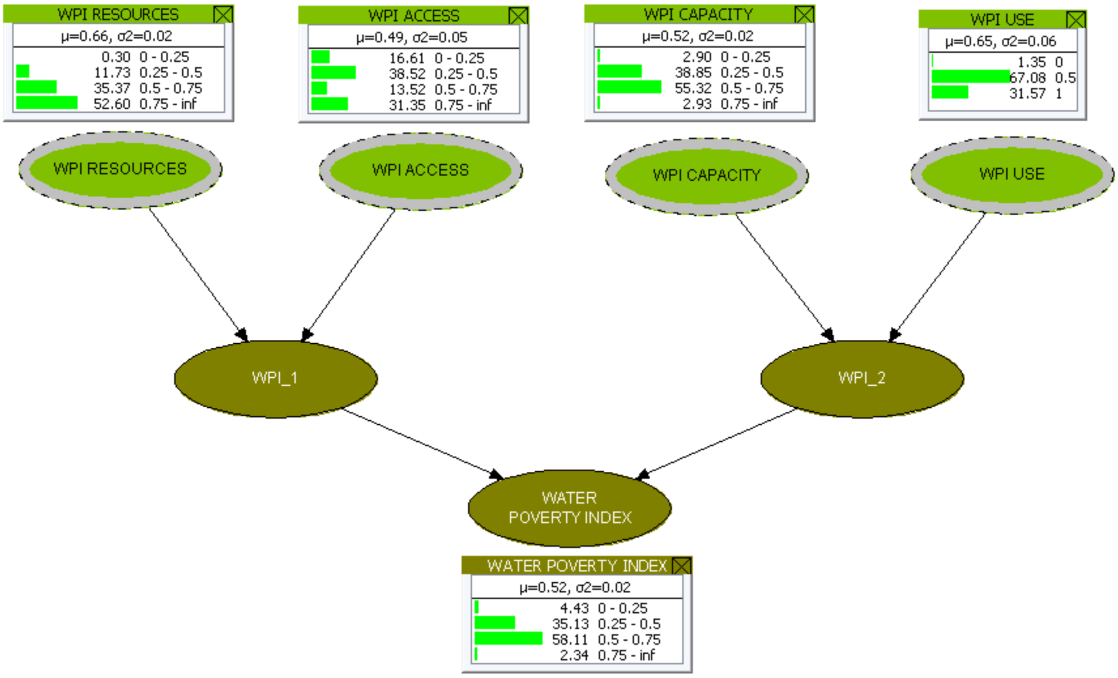
On the one hand, the Programme aspires to promote awareness creation, policy dissemination and appropriate support from relevant authorities and effective community management structures (e.g. WASH committees) to improved water resource management. The concern is not only for degradation of rivers and water catchments, where WRMA are committed to water resources conservation, but also at the micro-level. Inadequate designs of schemes to prevent source pollution and poor management of water points may lead to increased pollution of the water bodies, and building up recipient capacity is foreseen in this regard. A key aspect falls on adequate water quality surveillance and monitoring performance. As mentioned, especial attention should be given to key variables, even more, to those ones that present a highest level of uncertainty.

It can be seen in Figure 16 that the "Resources" component is the one that presents the highest improvement after project completion. In this regard, it shouldn't been forgotten its relationship with the aspects concerning the system maintenance.

On the other hand, the rural water supply component of the intervention includes in the intervention areas the development of water sources for new users (1.3 million beneficiaries) currently un-served, and the rehabilitation of existing dysfunctional water systems that will be used by additional 330,000 people. Various technological options will be employed to develop new sources, with strong emphasis on appropriate and local sustainable options (i.e. deep boreholes, rock catchments and rain water harvesting). In this regard, the project also will make investments into decreasing the per capita cost of water development.



(a)



(b)

Figure 16. Water Poverty Index final values: (a) No intervention; (b) WaSH Programme.

However, the results related to the "Access" variable, and contrary to what might be expected, the project investment is unlikely to achieve important improvements. According to Figure 16b, it is estimated that approximately half of the intervened area population still will not have access to safe and affordable drinking water after the Programme completion. A recent report from the WHO/UNICEF Joint Monitoring Programme (2015) estimates that only the 57% of the rural population of Kenya has access to safe drinking water (improved). This estimation, even if considers all the districts of the country and it is measured differently, it is aligned with the results obtained, being far to meet the Millennium Development Goals water targets.

5.2.3.Hygiene

According to the WaSH Programme, hygiene education and promotion is expected to be a core activity. Specifically, it will have differentiated two main components: promotion of behavioural changes and promotion of appropriate technology. The target is to cover 350,000 households (2 million people approximately) through direct marketing, though larger numbers are likely to be reached by mass marketing (e.g. radio, local newspapers and promotional campaigns). After project completion, in terms of hygiene promotion, it is expected that communities should have a good level of understanding of the link between poor hygiene and diseases.

On the other hand, the project will foster hygienic handling of water as well as point-of-use treatment. Technologies for treatment at the point of use will include solar disinfection, filtration and chlorination. It is assumed that direct beneficiaries of the Programme access potable water sources and that good hygiene will ensure safety at the point of use. For the un-served population, household water treatment is promoted to improve their drinking water from whatever source they use and thus ensure safety.

Finally, and with the new water supplies, some of the multiple uses of water (e.g. livestock watering, the production of fodder for animals, small-scale irrigation) are to be encouraged to increase food security and thus reduce the vulnerability of the people living in the areas.

The results presented in Figure 17b reveal that major impact after project completion is related to the “Hygiene Poverty Index” composite, which highlights that hygiene promotion might be a true cost effective intervention. However, the values of the overall index variables are the lowest ones and they still require a priority attention, especially to those aspects regarding hygienic behavioural issues.

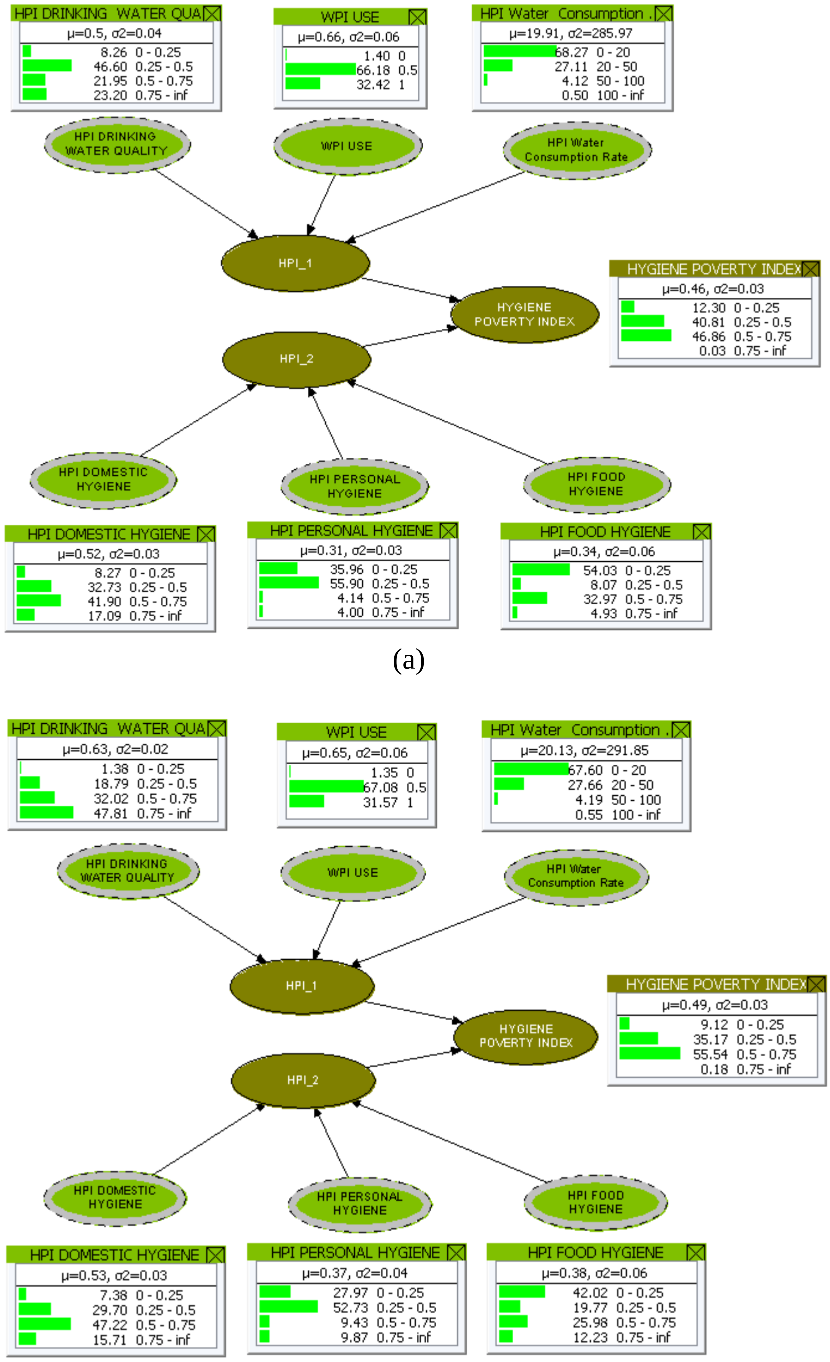
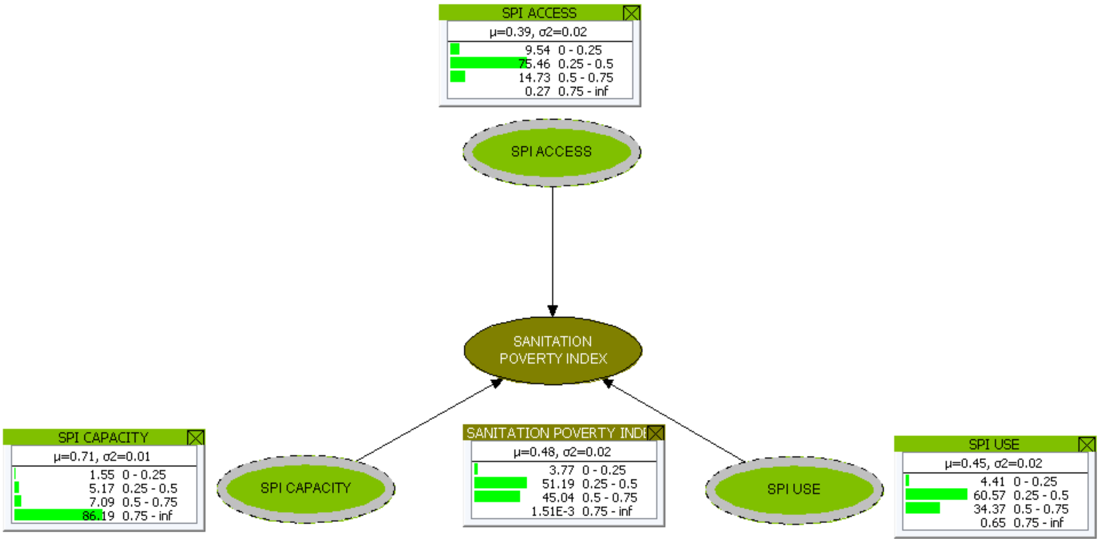


Figure 17. Hygiene Poverty Index final values: (a) No intervention; (b) WaSH Programme.

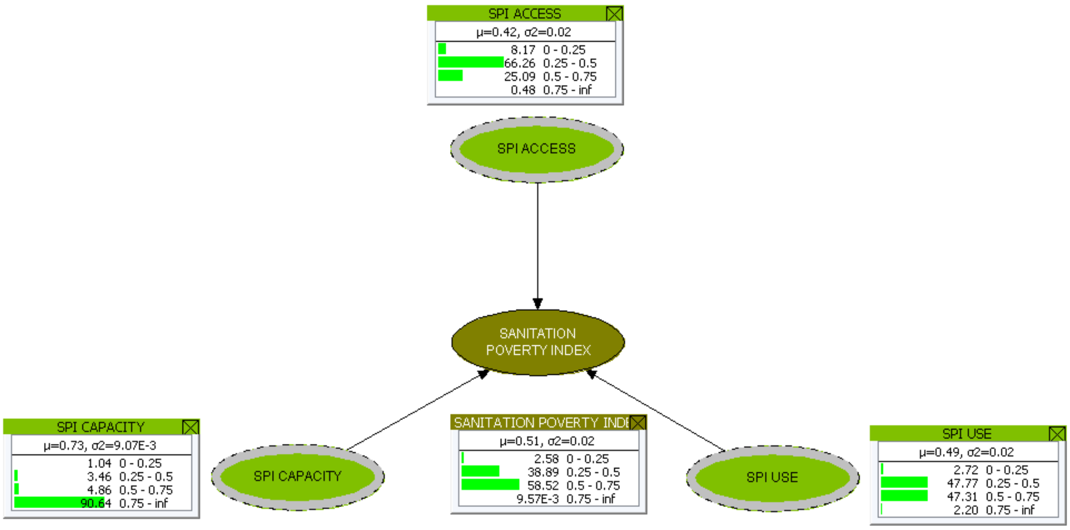
5.2.4.Sanitation

The promotion of household sanitation will be closely linked to the provision of water facilities and to promotion of hygiene. On the one hand, the sanitation component of the intervention includes, in the intervention areas, the construction of new latrines which will reach to around 1.6 million new beneficiaries. On the other hand, the implementation strategy relies on a competitive marketing approach, where 33,000 sanitation and hygiene promoters will be mobilised and trained in order to ensure that at least 217,000 households (1.3 million approximately) will properly use a toilet at home.

The results presented in Figure 18 show that, regardless the existing capacity to maintain the sanitation infrastructure, the project interventions are unlikely to achieve remarkable improvements. According to Figure 18b, results pointing the “Access” variable suggest that approximately 60% of the population will still lack of access to improved and affordable sanitation facilities after project completion. These results overpass more recent national estimations (WHO/UNICEF 2015), which state that limited improvement has been done and still 70% of the rural population lacks of access to an adequate sanitation infrastructure. Although both methodologies possess differences when measure accessibility to sanitation, these suggest that, as the case of access to safe drinking water, sanitation targets established by the Millennium Development Goals are far from being met.



(a)



(b)

Figure 18. Hygiene Poverty Index final values: (a) No intervention; (b) WaSH Programme.

5.3. Assessment of the WaSH Programme impact at district scale

As an overall assessment of the WaSH Programme impact was carried out previously, the same objective was pursued in this section but at district level. To do this, 50% of the total intervened area was taking into consideration (9 districts) as a representative number for the evaluation. It should be noted that the complexity increases with the number of sub-administrative units considered. Nevertheless, same observations might be taken into account regardless the scale of evaluation.

The Programme approach is based on a heterogeneous intervention. Water-related actions differ among the districts while measures regarding sanitation and hygiene are more balanced (see Annexe III). This last fact is not positive, since an approach focused on an equal distribution programme is likely to be inefficient.

A first look at the results presented in Table 19 provides an initial image regarding WaSH situation. A first overall assessment, before programme implementation, permits to conclude that all selected areas require urgent intervention, as maximum values are around 0.50, suggesting that all the population considered lacks of an appropriate situation, the “0.5” level.

In this context, and considering the values obtained, these were ranked from 1 (better situation, less priority) to 9 (worse situation, more priority). According to this ranking, the districts of Turkana and Wajir require a special attention as they present the lowest values in the three composites (WPI, SPI, HPI). Oppositely, Busia, Kajiado and Bondo districts present the highest valuation regarding water, sanitation and hygiene issues, respectively. Finally, Mwingi possesses the highest value in average, considering the three aspects.

After project completion, a second overall evaluation enables to observe that all districts suffer a positive impact but at different levels.

On the one hand, and regarding water-related issues, this improvement varies from 3% to 9%. As shown in Table 19, Marsabit, Kwale, Turkana and Wajir receive a mayor benefit from the intervention. According to the results, the Programme pointed out three of the four neediest areas obtaining a highest improvement. However, these districts still remain at the bottom of the ranking. This is not considered a negative aspect, since reducing disparities among districts are seem to be an appropriate approach. What it is argued here is just that different strategies might reduce even more the existing disparities.

On the other hand, more remarkable progresses are presented on sanitation and hygiene aspects (up to 10% to 16%). As these interventions were more homogeneous in all districts, it is pointed out a clear relationship between population and actions carried out. At the same time, it is observed the link between both composites, as districts with higher improvement in hygiene issues present parallel values in sanitation ones. In this way, Marsabit, Kwale, Mwingi and Bondo districts counted with a deeper intervention, since the same number of sanitation and hygiene promoters and construction of infrastructure were provided to a lower amount of inhabitants. Again, hygiene interventions might be defined as true cost-effective ones.

Going deeper into the analysis, it is interesting to observe the impact of individual actions. For example, paying attention to the training provided in order to improve water-points management and maintenance, 525 community groups received such capacity building at Busia district (see Annexe III). On the one hand, it should be highlighted that Busia presented a relative higher value of the “Capacity” variable before the Programme. On the other hand, this district received a special attention as more groups than any other district were trained. However, the improvement achieved is lower than other districts.

In the same way, more needed districts experience a higher improvement with a lower specific intervention (e.g. Turkana and Wajir). Consequently, and based on these results, decision-makers might rethink the designed strategy, when efforts are distributed among the intervened areas, if the objective searches for reducing as much as possible existing disparities.

What it has been argued in this section is the potential of ooBn to assess not only WaSH situation at specific locations but to establish priority actions according to the expected impact of a range of potential actions. In this context, managers would be provided with adequate information to define strategies that are efficient, effective, and sustainable.

		Water Poverty Index						Sanitation Poverty Index					Hygiene Poverty Index					
		R	A	C	U	**WPI**	**Rank WPI**	A	C	U	**SPI**	**Rank SPI**	DW	PH	F	DH	**HPI**	**Rank HPI**
Bondo	No Intervention	0.57	0.54	0.40	0.55	**0.45**	6	0.41	0.68	0.48	**0.49**	4	0.61	0.35	0.30	0.51	**0.45**	1
	WaSH Programme	0.68	0.57	0.45	0.56	**0.50**	(7)	0.45	0.75	0.55	**0.55**	(3)	0.74	0.47	0.39	0.52	**0.51**	(5)
	Improvement	0.11	0.03	0.05	0.01	**0.05**		0.04	0.07	0.07	**0.06**		0.13	0.12	0.09	0.01	**0.06**	
Busia	No Intervention	0.65	0.48	0.57	0.61	**0.54**	1	0.42	0.75	0.44	**0.50**	2	0.61	0.40	0.43	0.59	**0.53**	6
	WaSH Programme	0.70	0.48	0.60	0.61	**0.57**	(1)	0.44	0.75	0.47	**0.52**	(5)	0.67	0.43	0.46	0.59	**0.55**	(4)
	Improvement	0.05	-	0.03	-	**0.03**		0.02	-	0.03	**0.02**		0.06	0.03	0.03	-	**0.02**	
Kajiado	No Intervention	0.59	0.46	0.49	0.74	**0.50**	4	0.47	0.72	0.52	**0.54**	1	0.44	0.33	0.35	0.50	**0.47**	3
	WaSH Programme	0.68	0.46	0.52	0.74	**0.54**	(5)	0.51	0.73	0.57	**0.57**	(1)	0.58	0.41	0.41	0.50	**0.50**	(6)
	Improvement	0.09	-	0.03	-	**0.04**		0.04	0.01	0.05	**0.03**		0.14	0.08	0.06	-	**0.03**	
Kwale	No Intervention	0.50	0.46	0.49	0.59	**0.45**	7	0.43	0.72	0.44	**0.49**	5	0.53	0.37	0.26	0.57	**0.46**	5
	WaSH Programme	0.61	0.55	0.54	0.59	**0.53**	(6)	0.45	0.75	0.56	**0.57**	(2)	0.70	0.62	0.44	0.58	**0.58**	(1)
	Improvement	0.11	0.09	0.05	-	**0.08**		0.02	0.03	0.12	**0.08**		0.17	0.25	0.18	0.01	**0.12**	
Mandera	No Intervention	0.54	0.52	0.58	0.80	**0.52**	2	0.37	0.61	0.47	**0.45**	6	0.58	0.24	0.54	0.50	**0.47**	4
	WaSH Programme	0.63	0.52	0.58	0.80	**0.55**	(2)	0.40	0.61	0.51	**0.48**	(7)	0.68	0.28	0.56	0.51	**0.49**	(7)
	Improvement	0.09	-	-	-	**0.03**		0.03	-	0.04	**0.03**		0.10	0.04	0.08	0.01	**0.02**	
Marsabit	No Intervention	0.54	0.45	0.46	0.71	**0.46**	5	0.27	0.64	0.44	**0.39**	7	0.35	0.29	0.18	0.42	**0.38**	8
	WaSH Programme	0.64	0.54	0.56	0.71	**0.55**	(3)	031	0.75	0.59	**0.49**	(6)	0.67	0.55	0.40	0.52	**0.56**	(2)
	Improvement	0.10	0.09	0.10	-	**0.09**		0.04	0.11	0.15	**0.10**		0.32	0.26	0.22	0.10	**0.16**	
Mwingi	No Intervention	0.55	0.45	0.56	0.79	**0.51**	3	0.41	0.74	0.44	**0.49**	3	0.47	0.38	0.27	0.56	**0.48**	2
	WaSH Programme	0.64	0.49	0.57	0.79	**0.55**	(4)	0.46	0.75	0.53	**0.55**	(4)	0.70	0.56	0.40	0.56	**0.56**	(3)
	Improvement	0.09	0.04	0.01	-	**0.04**		0.05	0.01	0.09	**0.06**		0.23	0.16	0.13	-	**0.08**	
Turkana	No Intervention	0.59	0.46	0.25	0.79	**0.41**	8	0.25	0.61	0.40	**0.35**	9	0.34	0.23	0.40	0.55	**0.45**	7
	WaSH Programme	0.69	0.47	0.35	0.80	**0.48**	(8)	0.28	0.61	0.44	**0.38**	(9)	0.47	0.28	0.43	0.55	**0.49**	(8)
	Improvement	0.10	0.01	0.10	0.01	**0.07**		0.03	-	0.04	**0.03**		0.13	0.05	0.03	-	**0.04**	
Wajir	No Intervention	0.50	0.37	0.26	0.69	**0.35**	9	0.27	0.61	0.44	**0.38**	8	0.39	0.17	0.25	0.46	**0.38**	9
	WaSH Programme	0.61	0.38	0.33	0.69	**0.41**	(9)	0.29	0.61	0.48	**0.40**	(8)	0.57	0.23	0.30	0.47	**0.42**	(9)
	Improvement	0.11	0.01	0.07	-	**0.06**		0.02	-	0.04	**0.02**		0.18	0.06	0.05	0.01	**0.04**	
Minimum						0.35					0.35							0.38
						(0.41)					(0.38)							(0.42)
Maximum						0.54					0.54							0.53
						(0.57)					(0.57)							(0.58)
Mean						0.47					0.45							0.45
						(0.52)					(0.50)							(0.52)

Table 19. Results before and after project complention at distric level. The three composites of the WaSH-PI and their key variables are represented. In brackets, results after WaSH Programme.

5.4. Assessment of the impact of other simulated scenarios

In this section several scenarios have been simulated paying attention to key individual interventions aligned with the WaSH Programme. The primary objective is to measure the probabilistic variations of key variables and to detect underlying relationships among different dimensions. Simultaneously, this exercise might perform a first attempt to carry out a sensitivity analysis. In parallel, variables, where the opinion of experts played a key role (due to the higher degree of data uncertainty), are "disturbed" and results of key indicators are assessed in order to test the robustness of the networks.

5.4.1. Water Supply Capacity

Different interventions associated to the Programme approach were simulated setting them to 100%. According to the results shown in Table 20, those interventions improving community groups' capacity to manage and maintain the water-points are likely to present a more positive impact. At the same time, it can be noted that such interventions also affect other dimensions (i.e. drinking water quality, DW_{HPI}). However, any intervention sets to 100% is likely to achieve the same overall value of the Water Poverty Index.

On the other hand, strengthening spare parts supply is likely to have a similar impact in both water supply and hygiene dimension. Regarding institutional capacity, it should be highlighted that this action favours the likelihood to achieve higher results of the capacity variable.

Before WaSH Programme

	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	A	C	U	WPI	A	C	U	SPI	DW	PH	F	DH	HPI
Mean	0.56	0.47	0.49	0.66	0.48	0.39	0.71	0.45	0.47	0.50	0.31	0.34	0.52	0.46
Std Dev	0.14	0.22	0.14	0.24	0.14	0.14	0.10	0.14	0.14	0.17	0.20	0.26	0.20	0.17

After WaSH Programme

Institutional Capacity sets to 100%

	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	A	**C**	U	**WPI**	A	C	U	SPI	DW	PH	F	DH	HPI
Mean	0.56	0.47	**0.55**	0.66	**0.49**	0.39	0.71	0.45	0.47	0.50	0.31	0.34	0.52	0.46
Std Dev	0.14	0.22	**0.17**	0.24	**0.14**	0.14	0.10	0.14	0.14	0.17	0.20	0.26	0.20	0.17

Training in Management and Maintenance set to 100%														
	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	**A**	**C**	U	**WPI**	A	C	U	SPI	DW	PH	F	DH	HPI
Mean	0.56	**0.50**	**0.51**	0.66	**0.50**	0.39	0.71	0.45	0.47	0.50	0.31	0.34	0.52	0.46
Std Dev	0.14	**0.22**	**0.14**	0.24	**0.14**	0.14	0.10	0.14	0.14	0.17	0.20	0.26	0.20	0.17
Spare Parts Supply sets to 100%														
	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	**A**	**C**	U	**WPI**	A	C	U	SPI	DW	PH	F	DH	HPI
Mean	0.56	**0.48**	**0.53**	0.66	**0.50**	0.39	0.71	0.45	0.47	0.50	0.31	0.34	0.52	0.46
Std Dev	0.14	**0.22**	**0.14**	0.24	**0.14**	0.14	0.10	0.14	0.14	0.17	0.20	0.26	0.20	0.17
Note: In bold, those variables that present an improvement after simulated intervention														

Table 20. Results of WaSH-PI and its components when setting water supply capacity-related individual interventions to 100%.

Finally, it is interesting to mention the costs associated to these simulated scenarios. However, those interventions related to support spare parts chain is unlikely to be reliable. As an example, following paragraphs introduced the logical employed to estimate these costs.

Regarding the community groups which were expected to be trained, the starting point was set up considering the ideal water-points (WP) should exist at the intervened area. This number was estimated proportionally to the population, and considering 250 people served by water-point (WHO/SEARO 2005). As presented in Annexe I, this number reaches the value of 29,016 WP. Accordingly, it was estimated that the same amount of community groups should manage and maintain these WP.

In this way, and knowing that 20% of the community groups were already trained (obtained by post-processing the data of the Water-point questionnaire), then setting this intervention to 100% is translated into training the rest 80% (29,016 x 0.80 = 23,213). Finally, costs assignment follows the budget established by the Programme (see Annexe III for further calculations).

In Table 21, it can be seen that it exists a huge investment if the objective is to train the whole number of community groups. Nevertheless, it is thought that expected results due to this intervention might be higher than the ones presented, as these values are based in current evidences. In a long term Programme, the population of the CPTs with new evidences would provide different and more accurate results.

In addition to this, training the direct responsible of the water-point management and maintenance might assure a multiplicative effect within the community as well as playing a key role in terms of system sustainability.

Intervention	Unit	Number	Unit cost (US$)	Total (US$)
Institutional capacity	Persons	4,497 (1,900)	39	175,000 (74,000)
Training	Community groups	23,213 (4,147)	473	10,980,000 (1,961,000)
Support Spare Parts Supply	Action/District	4 x 18 (1 x 18)	5,000	360,000 (90,000)
Note: In brackets, investment carried out by the WaSH Programme. Without, intervention set to 100%.				

Table 21. Estimation of the investment for the simulated scenarios regarding water supply capacity interventions.

5.4.2. Water Supply

Setting the construction and rehabilitation of water-points to 100% is related to eliminating the population who currently spend for than half an hour hauling water. The results obtained related to "Access" variable should be interpreted carefully. The final value doesn't deal only with the physical access, which it would achieve the goal set up by the MDGs ("Access Service" node equal to 74%), but with issues related to affordability. This is why the overall impact of the cited intervention is unlikely to increase dramatically (see Table 22).

On the other hand, Table 22 suggests that actions regarding water quality surveillance seem to be positive ones, as there is an important variation in both water supply and hygiene dimensions. These are water quality-oriented interventions and their impact don't transcend into other important aspects.

Before WaSH Programme														
	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	A	C	U	WPI	A	C	U	SPI	DW	PH	F	DH	HPI
Mean	0.56	0.47	0.49	0.66	0.48	0.39	0.71	0.45	0.47	0.50	0.31	0.34	0.52	0.46
Std Dev	0.14	0.22	0.14	0.24	0.14	0.14	0.10	0.14	0.14	0.17	0.20	0.26	0.20	0.17
After WaSH Programme														
Construction and Rehabilitation of Water-points set to 100%														
	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	**A**	C	**U**	**WPI**	A	C	U	SPI	DW	PH	F	DH	HPI
Mean	0.56	**0.54**	0.49	0.66	**0.50**	0.39	0.71	0.45	0.47	0.50	0.31	0.34	0.52	0.46
Std Dev	0.14	**0.22**	0.14	0.24	**0.14**	0.14	0.10	0.14	0.14	0.17	0.20	0.26	0.20	0.17

Water Quality Surveillance sets to 100%														
	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	A	C	U	**WPI**	A	C	U	SPI	**DW**	PH	F	DH	HPI
Mean	**0.68**	0.47	0.49	0.66	**0.51**	0.39	0.71	0.45	0.47	**0.61**	0.31	0.34	0.52	0.46
Std Dev	**0.14**	0.22	0.14	0.24	**0.14**	0.14	0.10	0.14	0.14	**0.17**	0.20	0.26	0.20	0.17
Note: In bold, those variables that present an improvement after simulated intervention														

Table 22. Results of WaSH-PI and its components when setting water supply-related individual interventions at 100%.

As an attempt to quantify both simulations, an example is provided to illustrate the considerations carried out.

Regarding the construction of new water-points, two aspects were considered. On the one hand, from the cluster sampling household-survey (MICS) it was known that 43% of the population drank water from an improved source. In this way, the rest 57% did not. Considering this number and the ideal amount of WP, the required number of WP would be 29,016 x 0.57 = 16,539. At this point, it should be mentioned that the WaSH Programme accounted for constructing 5,961 new WP.

In this way, and considering that the task to find out which technology to employ was complex, it was adopted an economical approach that relates the WaSH Programme intervention with the one set to 100%. This is, it was established the ratio between both actions (16,539 / 5,961 = 2.77).

Then, if the construction of 5,961 new WP was associated to an investment of 21 millions of US$, the proposed investment would be 21 x 2.77 = 56.7 millions of US$.

Table 23 presents the huge difference between both hypothetical interventions. Although different in nature, these actions are equally important and complementary.

Intervention	Unit	Number	Unit cost (US$)	Total (US$)
Construction of WP	Different technologies	16,539 (5,961)	Depending on technology	56,700,000 (21,000,000)
Rehabilitation of WP	Different actions	240 (120)	Depending on action	2,400,000 (1,200,000)
Water Quality Surveillance	Action/District	4 x 18 (1 x 18)	94,000	6,768,000 (1,700,000)
Note: In brackets, investment carried out by the WaSH Programme. Without, intervention set to 100%.				

Table 23. Estimation of the investment for the simulated scenarios regarding water supply interventions.

5.4.3. Hygiene

As it was already mentioned, Table 24 shows that hygiene-related interventions are true cost-effective ones. It is clear that the reduction of water-related diseases depends on multiple improvements in home hygiene, aspects that require special attention and priority. At the same time, it should be noted that improving hygiene awareness would have a positive impact in sanitation-related issues.

Before WaSH Programme														
	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	A	C	U	WPI	A	C	U	SPI	DW	PH	F	DH	HPI
Mean	0.56	0.47	0.49	0.66	0.48	0.39	0.71	0.45	0.47	0.50	0.31	0.34	0.52	0.46
Std Dev	0.14	0.22	0.14	0.24	0.14	0.14	0.10	0.14	0.14	0.17	0.20	0.26	0.20	0.17
After WaSH Programme														
Hygiene interventions set to 100%														
	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	A	C	U	WPI	A	C	**U**	**SPI**	**DW**	**PH**	**F**	**DH**	**HPI**
Mean	0.56	0.47	0.49	0.66	0.48	0.39	0.71	**0.56**	**0.53**	**0.68**	**0.56**	**0.52**	**0.53**	**0.58**
Std Dev	0.14	0.22	0.14	0.24	0.14	0.14	0.10	**0.14**	**0.14**	**0.17**	**0.20**	**0.26**	**0.20**	**0.17**
Note: In bold, those variables that present an improvement after simulated intervention														

Table 24. Results of WaSH-PI and its components when setting hygiene-related individual interventions to 100%.

In other to assure the population of the intervened districts to practise appropriate hygiene habits, further efforts must be given. Specifically, setting this action to 100% is translated into approximately a quadruple investment (see Table 25). In Annexe III, procedures carried out to estimate costs are detailed.

Intervention	Unit	Number	Unit cost (US$)	Total (US$)
Training of hygiene trainers	Trainer	4,121 (900)	600	2,472,000 (540,000)
Training of hygiene promoters	Hygiene promoter	151,000 (33,000)	100	15,100,000 (3,300,000)
Hygiene education through direct marketing	Household	1,200,000 (350,000)	4	4,800,000 (1,400,000)
Promotion of point of use water treatment	Household	1,200,000 (350,000)	0,50	600,000 (175,000)
Hand-washing promotion (mass and direct marketing)	Action/District	3 x 18 (1 x 18)	50,000	2,700,000 (900,000)
Note: In brackets, investment carried out by the WaSH Programme. Without, intervention set to 100%.				

Table 25. Estimation of the investment for the simulated scenarios regarding hygiene interventions.

5.4.4. Sanitation

As it was observed when providing the population with access to water, a simulation where latrine construction is set to 100% would achieve the goal established by the MDGs. However, obtained results show that this value is not reached. The underlying reason falls on the existing high level of open defecation (41%). This is, for this simulation, the existing value was maintained constant due to the fact it was not known how the construction of latrines would modify this behaviour. Cultural beliefs and lack of awareness regarding health benefits could be shown up as a constraint of this regard.

On the other hand, Table 26 shows that this intervention is likely to have a more positive impact.

Before WaSH Programme

	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	A	C	U	WPI	A	C	U	SPI	DW	PH	F	DH	HPI
Mean	0.56	0.47	0.49	0.66	0.48	0.39	0.71	0.45	0.47	0.50	0.31	0.34	0.52	0.46
Std Dev	0.14	0.22	0.14	0.24	0.14	0.14	0.10	0.14	0.14	0.17	0.20	0.26	0.20	0.17

After WaSH Programme

Construction of latrines sets to 100%

	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	A	C	U	WPI	**A**	**C**	**U**	**SPI**	DW	PH	F	DH	HPI
Mean	0.56	0.47	0.49	0.66	0.48	**0.63**	**0.73**	**0.54**	**0.59**	0.50	0.31	0.34	0.52	0.46
Std Dev	0.14	0.22	0.14	0.24	0.14	**0.14**	**0.10**	**0.14**	**0.14**	0.17	0.20	0.26	0.20	0.17

Technical Training sets to 100%

	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	A	C	U	WPI	A	**C**	U	**SPI**	DW	PH	F	DH	HPI
Mean	0.56	0.47	0.49	0.66	0.48	0.39	**0.75**	0.45	**0.49**	0.50	0.31	0.34	0.52	0.46
Std Dev	0.14	0.22	0.14	0.24	0.14	0.14	**0.10**	0.14	**0.14**	0.17	0.20	0.26	0.20	0.17

Materials Distribution sets to 100%

	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	A	C	U	WPI	A	**C**	U	**SPI**	DW	PH	F	DH	HPI
Mean	0.56	0.47	0.49	0.66	0.48	0.39	**0.75**	0.45	**0.49**	0.50	0.31	0.34	0.52	0.46
Std Dev	0.14	0.22	0.14	0.24	0.14	0.14	**0.10**	0.14	**0.14**	0.17	0.20	0.26	0.20	0.17

Note: In bold, those variables that present an improvement after simulated intervention

Table 26. Results of WaSH-PI and its components when setting sanitation-related individual interventions to 100%.

Finally, Table 27 details, in terms of investment effort, the simulated scenarios. Apart from the remarkable value regarding latrine construction, it is interesting to observe the difference between the other two scenarios where, for similar results (see Table 26), the economical expense varies considerably. However, complexity and nature of these interventions provide a fact for this difference. In Annexe III, procedures developed to estimate costs are detailed.

Intervention	Unit	Number	Unit cost (US$)	Total (US$)
Construction of latrines	Latrine	1,070,000 (310,000)	21	22,470,000 (6,510,000)
Technical training	Promoters	5,803 (3,000)	28	162,000 (84,000)
Material Distribution	Local production units	4,352 (1,800)	400	1,740,800 (720,000)
Note: In brackets, investment carried out by the WaSH Programme. Without, intervention set to 100%.				

Table 27. Estimation of the investment for the simulated scenarios regarding sanitation interventions.

5.4.5. Expert knowledge involvement

As introduced, it was considered appropriate to test the robustness of the networks by dealing with those nodes that i) present a higher degree of uncertainty, ii) represent an important role within the networks, and iii) are constructed by using mathematical expressions. Different nodes from the overall networks were selected and important changes in their algorithms were introduced. The objective of this exercise was to assess how these "disturbances" affected the networks, or more precisely, key nodes. Results are presenting according to the different networks developed.

Water Supply Capacity sub-network

The "Capacity" node was chosen regarding this network. According to Section 4.2.1, this node is affected by two other nodes, namely "Management System" and "Maintenance System". Regarding this configuration, experts might differ whether it might be more important and, if so, to which extent. The original construction of this relationship attended the following expression:

CAPACITY = (1/2 x Maintenance System) + (1/2 x Management System)

Four different scenarios were simulated from the initial one. The relative importance between variables were doubled and tripled, experimenting each variable an increase or decrease of 25% and 50%. When doing this, and considering the expression above, result are compensated, so final values might be over or under the initial ones.

	Management System	Maintenance System
Initial Scenario	0.5	0.5
Scenario 1	0.66 (+32%)	0.34 (-32%)
Scenario 2	0.34 (-32%)	0.66 (+32%)
Scenario 3	0.75 (+50%)	0.25 (-50%)
Scenario 4	0.25 (-50%)	0.75 (+50%)
Note: In brackets, variation from initial scenario		

Table 28. Simulated scenarios regarding the relative importance of involved nodes that affect "Capacity" variable.

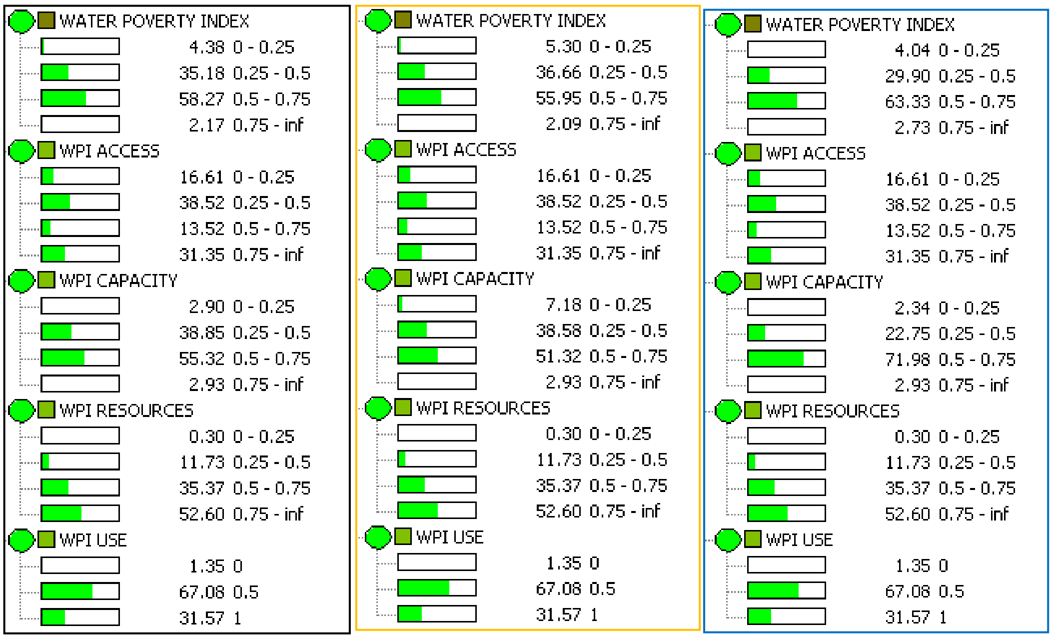


Figure 19. Disturbances subjected to "Capacity" variable. In black, original scenario; In orange, scenario 1; In blue, scenario 2.

	Water Poverty Index				
	R	A	C	U	WPI
Original scenario	0.66	0.49	0.52	0.65	0.52
Scenario 1	0.66	0.49	**0.50 (-4%)**	0.65	**0.51 (-1%)**
Scenario 2	0.66	0.49	**0.56 (+12%)**	0.65	**0.53 (+1%)**

Table 29. Key nodes values regarding the simulated scenarios. In bold, those variables experimenting a change, expressed in relative percentage.

Figure 19 shows the results obtained when simulating scenarios "1" and "2". At this point, it should be mentioned that the task to evaluate the changes of key nodes by looking at the probability functions might be difficult for the reader. In this way, tables expressing mean values of relevant variables will complement this information. However, as means might vary slightly, probability distributions reflect these changes clearly and so are they provided.

In this example, disturbed nodes are directly linked to the "Capacity" variable and consequently, their effect might be noted in a higher degree. Nevertheless, only when increasing the relative importance of "Maintenance System", impacts are notable. Although assessed variable presents a maximum change in its value up to 12% (in relative terms), it is much lower than the disturbance carried out. On the other hand, it should be highlighted that the overall Water Poverty Index (WPI) slightly changes, suggesting that the effect through the network softens (see Table 29).

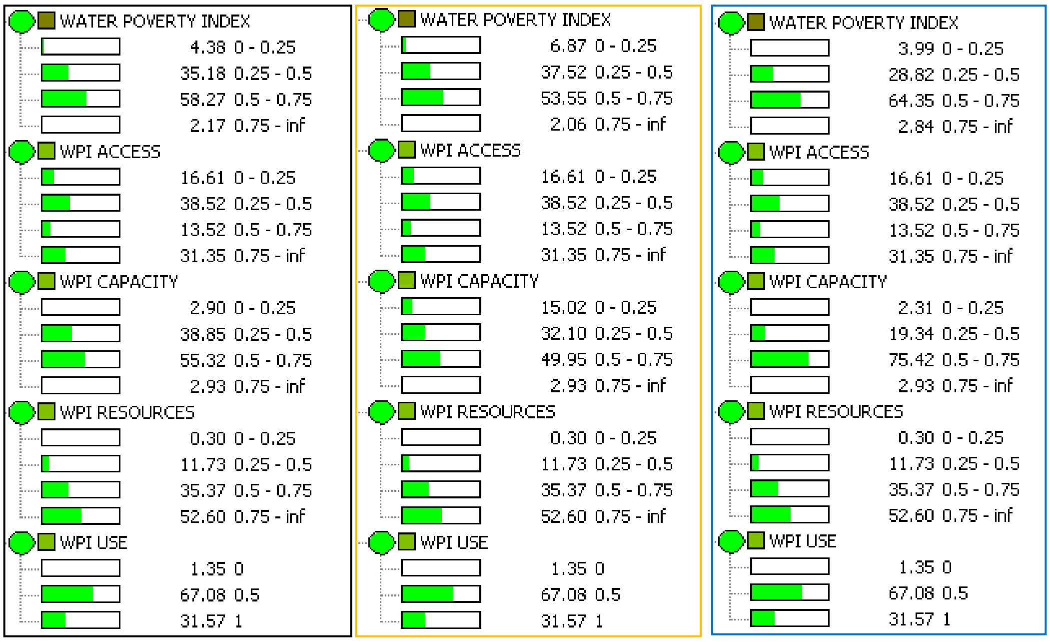


Figure 20. Disturbances subjected to "Capacity" variable. In black, original scenario; In orange, scenario 3; In blue, scenario 4.

	Water Poverty Index				
	R	A	C	U	WPI
Original scenario	0.66	0.49	0.52	0.65	0.52
Scenario 3	0.66	0.49	**0.47 (-10%)**	0.65	**0.50 (-4%)**
Scenario 4	0.66	0.49	**0.57 (+10%)**	0.65	**0.54 (+4%)**

Table 30. Key nodes values regarding the simulated scenarios. In bold, those variables experimenting a change, expressed in relative percentage.

When simulating the remaining scenarios, it can be observed from Table 30 that the impacts are higher (up to 10%). However, these changes remain lower than the disturbances provided (up to 50%). Again, more remarkable effects are seen in relation to "Capacity" variable. As previously, this effect softens when propagating through the network.

Water Supply sub-network

"Water Quality" variable is presented as an important sectoral aspect. As pointed Giné Garriga et al. (2013), water quality analysis has long been nearly absent from water coverage assessments because of affordability issues. In addition to this, it is argued that assuming that improved water-points always deliver safe water is over-optimistic. Furthermore, it is stated that water quality surveillance does not significantly impact on the overall cost of the mapping exercise. With all this in mind, there might be a debate where experts discuss the relative importance of these aspects. Due to this reason, and regarding the impact of "Water Quality" node in other dimensions, this variable was chosen and the scenarios shown in Table 31 were simulated.

As before, it is introduced the original construction of the selected variable:

Water Quality = (1/2 x Sanitary Risk) + (1/2 x Water Quality Surveillance)

	Sanitary Risk	Water Quality Surveillance
Initial Scenario	0.5	0.5
Scenario 1	0.66 (+32%)	0.34 (-32%)
Scenario 2	0.34 (-32%)	0.66 (+32%)
Scenario 3	0.75 (+50%)	0.25 (-50%)
Scenario 4	0.25 (-50%)	0.75 (+50%)
Note: In brackets, variation from initial scenario		

Table 31. Simulated scenarios regarding the relative importance of involved nodes that affect "Water Quality" variable.

In order to simplify, only simulated scenarios, where the variability of the results were higher, are shown (see Figure 21). However, it can be seen that the impacts on directly linked nodes (i.e. "HPI Drinking Water Quality") are far from be remarkable (2%). Simultaneously, the effects on final indexes (i.e. "WPI" and "HPI") are inexistent (see Table 32).

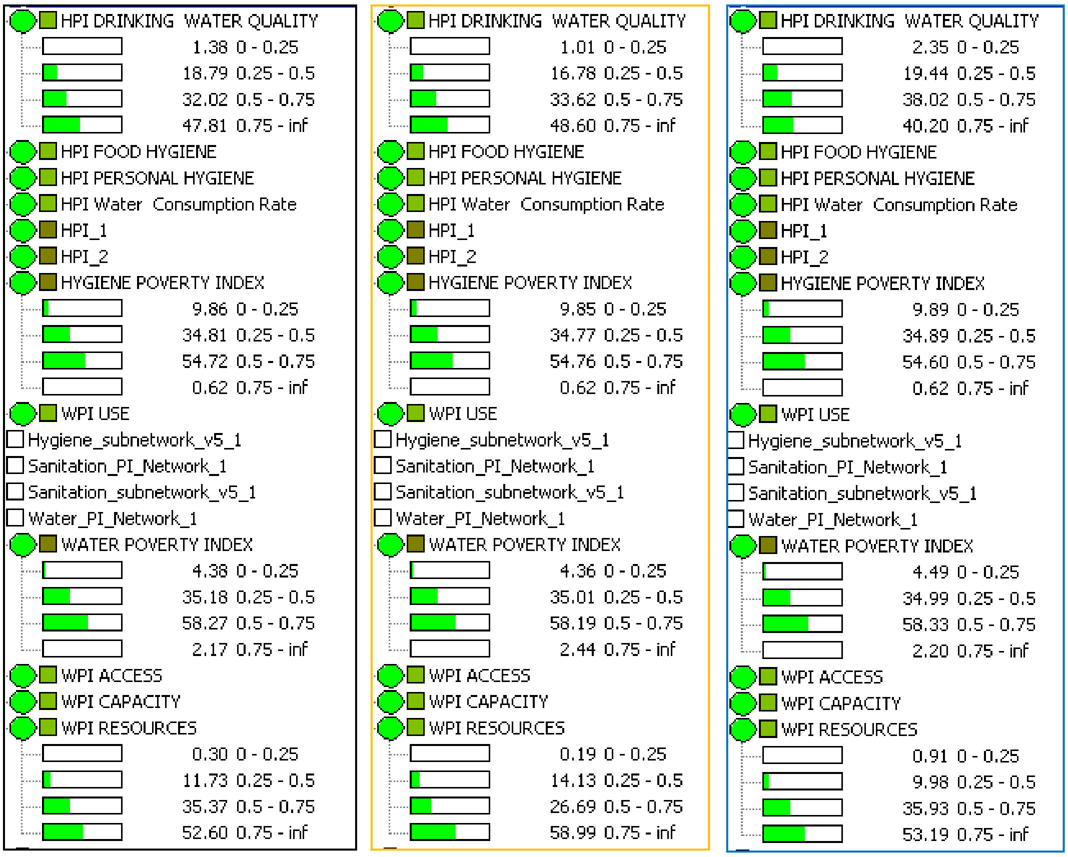


Figure 21. Disturbances subjected to "Water Quality" variable. In black, original scenario; In orange, scenario 3; In blue, scenario 4.

	Water Poverty Index		Hygiene Poverty Index	
	R	WPI	DW	HPI
Original scenario	0.66	0.52	0.63	0.49
Scenario 3	0.66	0.52	**0.64 (+2%)**	0.49
Scenario 4	0.66	0.52	**0.62 (-2%)**	0.49

Table 32. Key nodes values regarding the simulated scenarios. In bold, those variables experimenting a change, expressed in relative percentage.

Hygiene sub-network

In this case, and due to the considerable amount of nodes that are affected, "Hygiene Awareness" variable was selected to analyse its impact on those nodes when disturbed. In addition to this, there might be a discussion regarding the relative importance of the variables that construct this node. Following previous examples, several scenarios were simulated and only more remarkable impacts are presented as a simplification.

As done, it is introduced the original construction of the selected variable:

Hygiene Awareness = (1/2 x Educational Level) + (1/2 x Hygiene Education)

	Educational Level	Hygiene Education
Initial Scenario	0.5	0.5
Scenario 1	0.66 (+32%)	0.34 (-32%)
Scenario 2	0.34 (-32%)	0.66 (+32%)
Scenario 3	0.75 (+50%)	0.25 (-50%)
Scenario 4	0.25 (-50%)	0.75 (+50%)
Note: In brackets, variation from initial scenario		

Table 33. Simulated scenarios regarding the relative importance of involved nodes that affect "Hygiene Awareness" variable.

Results shown in Table 34 follow the same tendency that previous comments. This is, there are slight impacts on directly related nodes (up to 4%) and no meaningful ones in overall indexes (up to 2%). As "Hygiene Awareness" variable transcends different dimensions, in this example, it is interesting to point out that only changes take place on "SPI Use" and "SPI" nodes.

	Sanitation Poverty Index				Hygiene Poverty Index				
	A	C	U	SPI	DW	PH	F	DH	HPI
Initial Scenario	0.42	0.73	0.49	0.51	0.63	0.37	0.38	0.52	0.49
Scenario 1	0.42	0.73	**0.48 (-2%)**	**0.50 (-2%)**	0.63	0.37	0.38	0.52	0.49
Scenario 2	0.42	0.73	**0.47 (-4%)**	**0.50 (-2%)**	0.63	0.37	0.38	0.52	0.49

Table 34. Key nodes values regarding the simulated scenarios. In bold, those variables experimenting a change, expressed in relative percentage.

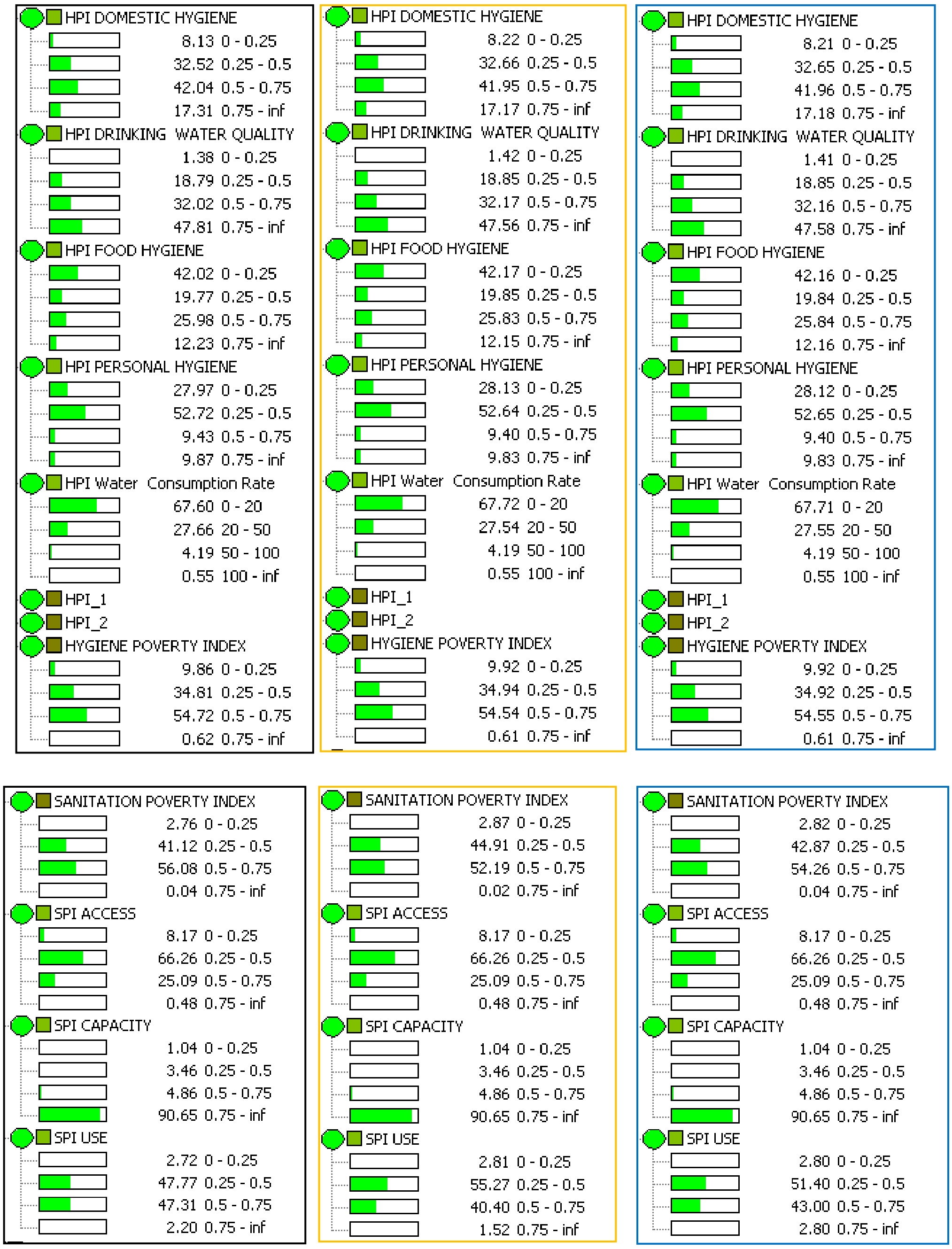


Figure 22. Disturbances subjected to "Hygiene Awareness" variable. In black, original scenario; In orange, scenario 1; In blue, scenario 2.

Sanitation sub-network

As a last example, a node constructed by three other nodes was selected and six different scenarios were simulated (see Table 35). When dealing with a higher quantity of factors, uncertainty increases as well. Within the networks, nodes constructed by several different nodes are not common. These existing cases were tested and only the most representative is presented.

As before, it is introduced the original construction of the selected variable:

Access to Improved WP = (1/3 x Construction Latrines) + (1/3 x Affordability) + (1/3 x Improved Sanitation)

	Construction Latrines	Affordability	Improved Sanitation (%)
Initial Scenario	0.33	0.33	0.33
Scenario 1	0.50 (+51%)	0.25 (-24%)	0.25 (-24%)
Scenario 2	0.25 (-24%)	0.50 (+51%)	0.25 (-24%)
Scenario 3	0.25 (-24%)	0.25 (-24%)	0.50 (+51%)
Scenario 4	0.75 (+127%)	0.125 (-62%)	0.125 (-62%)
Scenario 5	0.125 (-62%)	0.75 (+127%)	0.125 (-62%)
Scenario 6	0.125 (-62%)	0.125 (-62%)	0.75 (+127%)
Note: In brackets, variation from initial scenario			

Table 35. Simulated scenarios regarding the relative importance of involved nodes that affect "Access to Improved Water-points" variable.

As expected, and due to the higher disturbances provided, impacts on key variables appear to be remarkable as well (see Table 36). The simulation of scenario "6", when increasing the relative importance of "Improved Sanitation" node, is presented as the one where more changes appear (up to 12%). Nevertheless, it should be highlighted that these impacts remain low, as disturbances provided to the selected variables reach a higher order of magnitude.

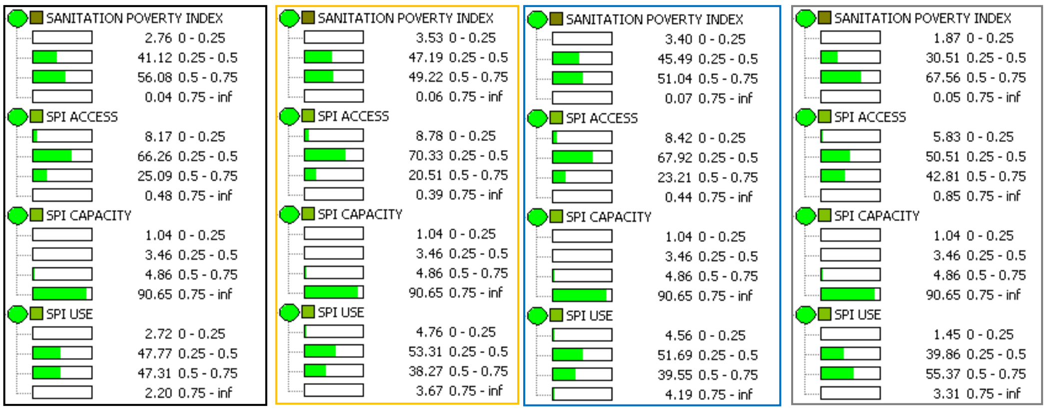


Figure 23. Disturbances subjected to "Access to Improved Sanitation" variable. In black, original scenario; In orange, scenario 4; In blue, scenario 5; In grey, scenario 6.

	Sanitation Poverty Index			
	A	C	U	SPI
Initial Scenario	0.42	0.73	0.49	0.51
Scenario 4	**0.41 (-2%)**	0.73	**0.47 (-4%)**	**0.49 (-4%)**
Scenario 5	**0.41 (-2%)**	0.73	**0.48 (-2%)**	**0.49 (-4%)**
Scenario 6	**0.47 (+12%)**	0.73	**0.52 (+6%)**	**0.54 (+6%)**

Table 36. Key nodes values regarding the simulated scenarios. In bold, those variables experimenting a change, expressed in relative percentage.

In this section, as a brief, several interventions set to 100% were simulated independently. It has been shown that sanitation-related actions have the most remarkable impact when assessing these simulations. The rest of modelled interventions affect in a variety of ranges. Simultaneously, there was the possibility to establish the relationships of the individual actions among the different dimensions. In parallel, key variables, where the opinion of experts played a key role, were subjected to different disturbances. Results showed that relative slight changes took place when propagating modifications through the network. Consequently, such exercise permits to conclude that the proposed ooBn possesses an acceptable degree of robustness. Finally, some of these scenarios were quantified in economical terms. In this way, interventions might be fixed in order to assess their impacts and translate them into investments efforts. Inversely, and as it will be presented in next section, investments might be fixed, establishing different interventions, in order to evaluate their impacts.

5.5. ooBns as a tool for sector planning

As a final attempt to explore the potential of this DSS, the manner of understanding the problem was conceptualised backwards. This is, a hypothetical desire result variable was fixed in order to infer which values of its parents would satisfy this condition. In this way, it would possible to design focus-oriented strategies to improve those selected targets.

Specifically, the results of the three composites were fixed and it was obtained the results of their parent nodes ("Objective" nodes). In an ideal situation, this exercise should be able to propagate the results (in form of probabilities) from the final index node to the intervention nodes mentioned in Section 5.1. However, and even if it is theoretically possible, the complexity of this last exercise carried out with the specific software didn't allow this goal to be achieved completely.

In this way, three different simulations were carried out regarding the three composites of the WaSH-PI.

5.5.1. Water Poverty Index

Firstly, it should be mentioned that once the network is created through the definition of all nodes and their links, these relationships are kept when running the network backwards. Consequently, new links are created and the complexity to populate the CPTs increase notably (see Figure 24). For this reason, a partial exercise was done with the objective to present the potential of ooBn as a tool for sector planning.

In this case, the values of the partial indexes were fixed. Specifically, these values are aligned with the same magnitude-order stated by the MDGs (in this case, halving the population with inappropriate WaSH-PI values). Figure 25 shows that in other to achieve the required probability function (or desirable results), taking as starting point the results after the WaSH Programme, remarkable improvements must be done. According to the results, aspects that need a deeper intervention are those ones related to access to water (in terms of physical accessibility and affordability) and to achieve the capacity building programmes' goals. It is important to mention that different combinations were used to construct the partial indexes, obtaining similar results.

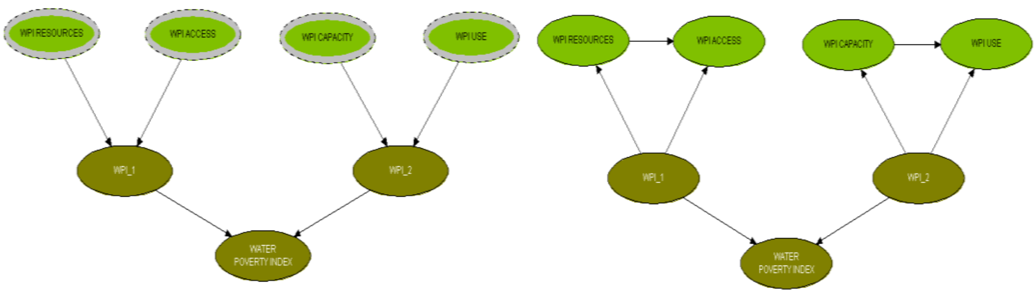


Figure 24. Representation of the inversion of several links and related new created relationships.

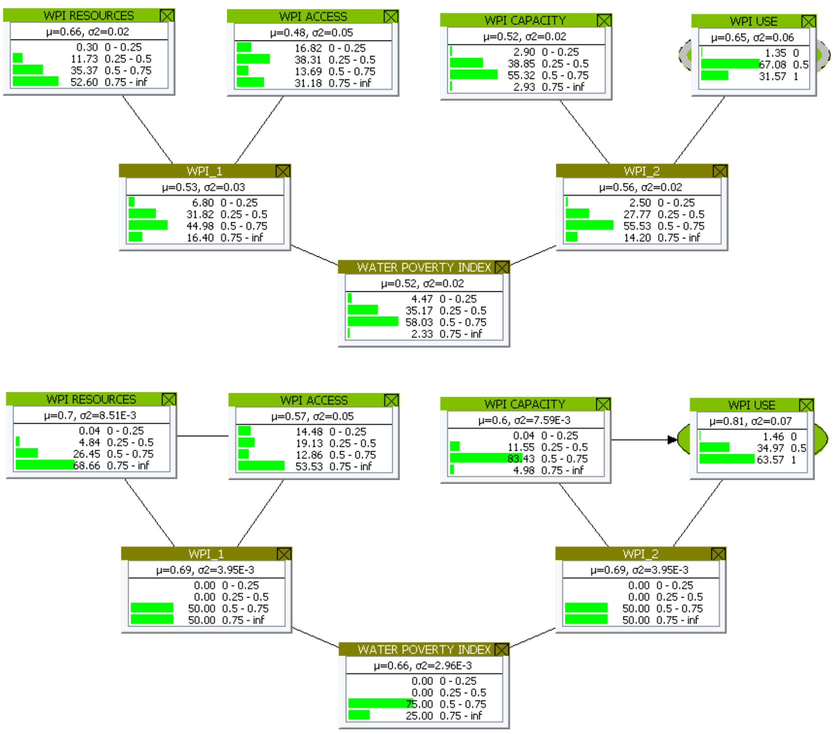


Figure 25. Estimation of water-related improvements to carried out in order to achieve expected results. WaSH Programme results are considering as a starting point.

These results are translated into the need of constructing an important number of water-points, as well as establishing fair tariffs for water payment. At the same time, trainings in management and maintenance should be controlled periodically in order to assess their effectiveness. In the same way, water quality surveillance needs to be improved in order to achieve the expected results.

In economic terms, considering the calculation processes and results in Section 5.4.1 and 5.4.2 and as a proxy, it could be identify and quantify the actions presented in Table 37. As shown, efforts must be tripled to achieve hypothetical desired results.

Intervention	Unit	Number	Unit cost (US$)	Total (US$)
Construction of WP	Different technologies	15,000 (5,961)	Depending on technology	52,500,000 (21,000,000)
Training	Community groups	23,213 (4,147)	473	10,980,000 (1,961,530)
Support Spare Parts Supply	Action/District	4 x 18 (1 x 18)	5,000	360,000 (90,000)
Total				63,840,000 (23,051,530)
Note: In brackets, investment carried out by the WaSH Programme. Without, investment needed to achieve fixed objectives.				

Table 37. Estimation of the envisaged investment according to the specific goals fixed regarding water-related issues.

5.5.2. Sanitation Poverty Index

In this case, and taking into account that the results regarding the capacity of constructing and maintaining the sanitation infrastructure (in terms of skills and availability of materials) were already appropriate, this node kept the direction and direction of its link (see Figure 26). In brief, this tool permits to focus on specific objectives.

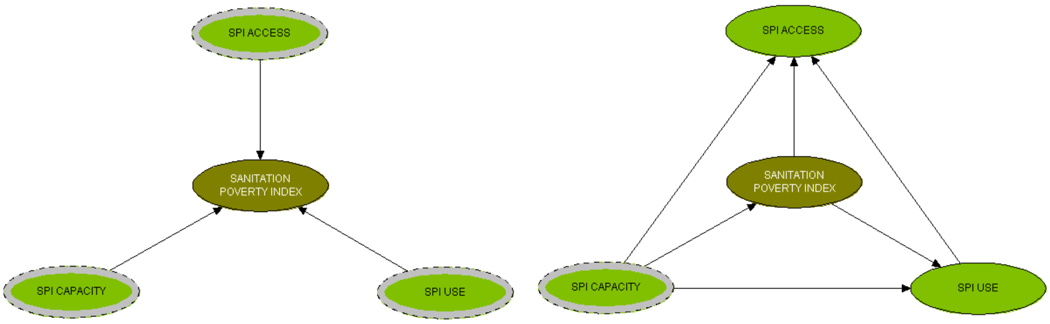


Figure 26. Representation of the inversion of several links and related new created relationships.

The results obtained (see Figure 27) suggest that special attention should be given to the construction of latrines. Equally important, and as mentioned, promotion of improved hygiene practices, including appropriate use and maintenance of the sanitation facilities, is an important intervention to carry out, as all these measures will help increase sanitation coverage and health benefits (Cairncross and Valdmanis 2006). In this case, it was opted to fix a more ambitious objective than the previous section. According to results shown in Section 5.4.4, the impact of constructing a remarkable amount of latrines would be higher than other simulated interventions.

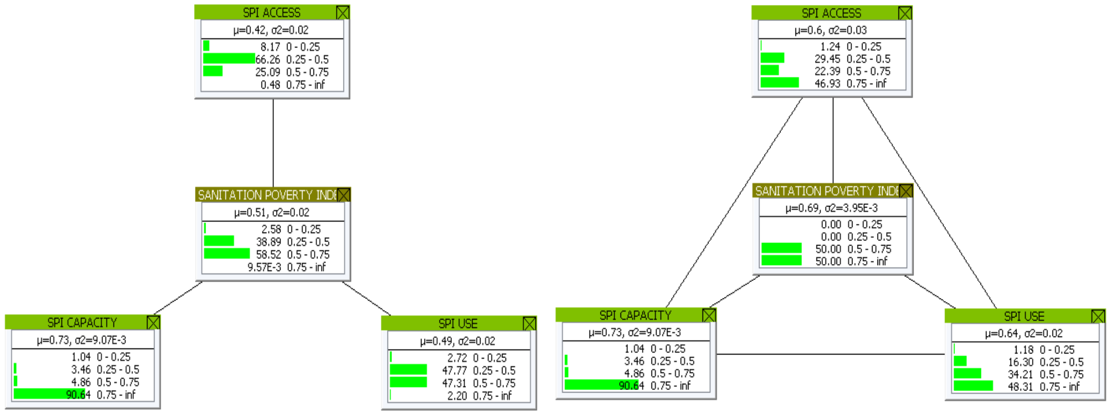


Figure 27. Estimation of sanitation-related improvements to carried out in order to achieve expected results. WaSH Programme results are considering as a starting point.

Finally, and according to Section 5.4.4, the expected investment might be detailed as presented in Table 38. It should be noted, that it is not require constructing latrines for all the population, as desirable results are reached providing improved sanitation facilities to 70% of the population.

Intervention	Unit	Number	Unit cost (US$)	Total (US$)
Construction of latrines	Latrine	850,000 (310,000)	21	17,850,000 (6,510,000)
Technical training	Promoters	3,000 (3,000)	28	84,000 (84,000)
Material Distribution	Local production units	1,800 (1,800)	400	720,000 (720,000)
Total				18,654,000 (7,314,000)
Note: In brackets, investment carried out by the WaSH Programme. Without, investment needed to achieve fixed objectives.				

Table 38. Estimation of the envisaged investment according to the specific goals fixed regarding sanitation-related issues.

It can be seen from Table 38 that sanitation-related issues require, multiplying by 2.5, increasing the economical efforts in order to achieve the desirable situation.

5.5.3. Hygiene Poverty Index

As it was presented in this Section, there is also the possibility to focus on specific objectives when designing specific strategies. In this case, the target is directed to hygienic habits (see Figure 28). As hygiene-related interventions also impact significantly in both sanitation and hygiene dimensions (see Section 5.4.3), again the desirable target was set up at ambitious level. This is, it was fixed expecting that there would have been a 50% of probability that, after interventions carried out, people practise “acceptable” (interval 0.50 - 0.75) or “good” (interval 0.75 - 1) hygienic practises.

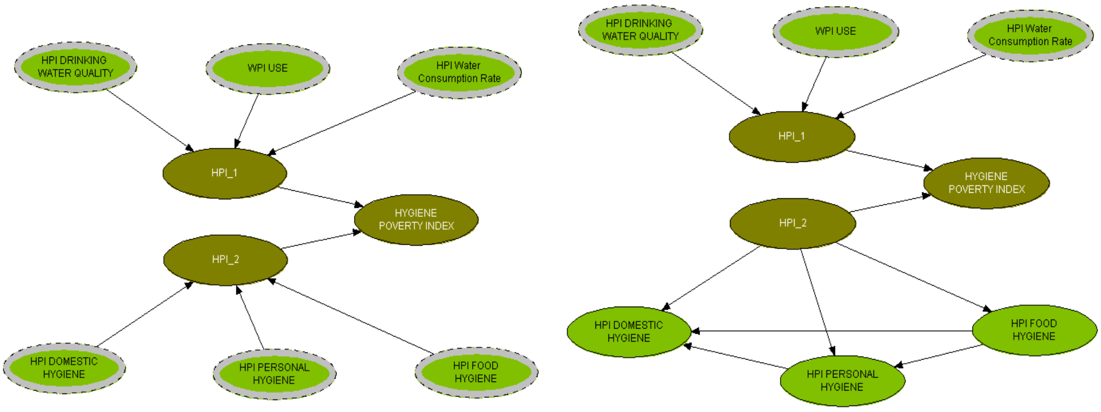


Figure 28. Representation of the inversion of several links and related new created relationships.

The results showed in Figure 29 quantify, to some extent, the improvement needed to achieve the desirable impact. Numerically, the values regarding hygienic habits should be doubled.

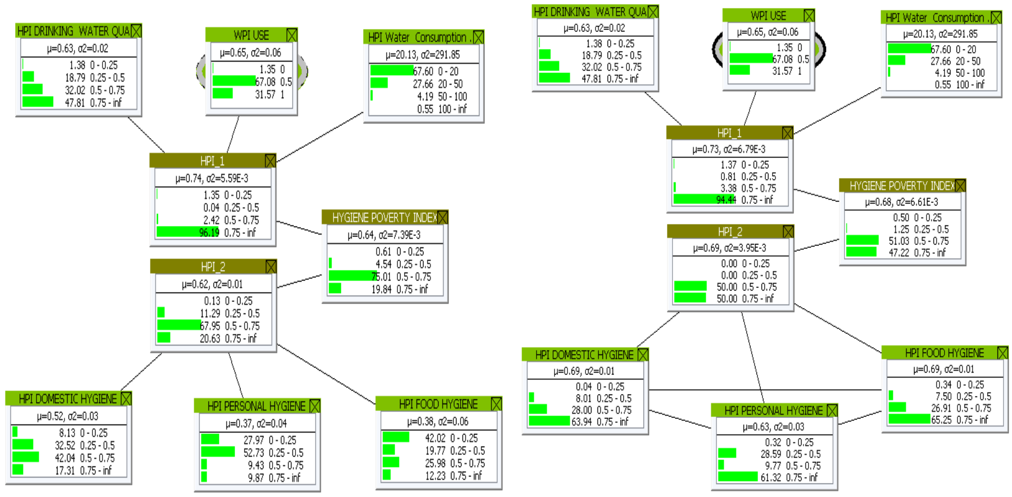


Figure 29. Estimation of hygiene-related improvements to carried out in order to achieve expected results. WaSH Programme results are considering as a starting point.

Finally, and considering the simulated scenarios of Section 5.4.3, an estimation of the economical investment is detailed in Table 39. These results suggest that related actions must be set to 100%. However, it should be highlighted that as far new evidences from these interventions are collected, these estimations might vary significantly.

Intervention	Unit	Number	Unit cost (US$)	Total (US$)
Training of hygiene trainers	Trainer	4,121 (900)	600	2,472,000 (540,000)
Training of hygiene promoters	Hygiene promoter	151,000 (33,000)	100	15,100,000 (3,300,000)
Hygiene education through direct marketing	Household	1,200,000 (350,000)	4	4,800,000 (1,400,000)
Hand-washing promotion, mass and direct marketing	Action/District	3 x 18 (1 x 18)	50,000	2,700,000 (900,000)
Total				25,072,000 (6,140,000)
Note: In brackets, investment carried out by the WaSH Programme. Without, investment needed to achieve fixed objectives.				

Table 39. Estimation of the envisaged investment according to the specific goals fixed regarding hygiene-related issues.

Table 40 summarizes envisaged investment for the targets fixed. Notably, water-related issues, because of the nature of its intervention, requires a higher economical effort.

Dimension	Investment by targets (US$)	Investment WaSH Programme (US$)	Difference (US$)
Water	63,840,000	23,051,000	40,789,000
Sanitation	18,654,000	7,314,000	11,340,000
Hygiene	25,072,000	6,140,000	18,932,000
Total	**107,566,000**	**36,505,000**	**70,521,000**

Table 40. Comparison between investment carried out by WaSH Programme and economical effort required regarding different fixed targets.

Nevertheless, this not trivial investment might not be afforded by any government or external donor. In this way, and considering that sanitation and hygiene interventions are likely to generate more positive impacts, a redistribution of the budget provided by the WaSH Programme could be an option. As demonstrated, such flexibility is provided by using an ooBn approach.

An illustrative example is provided. A hypothetical scenario is simulated (SS), where 5 millions of US$, destined to water-related interventions, are redistributed. This is translated into a reduction of new constructed water-points (supplying 22% to 14% of the population) and community groups trained (from 14% to 7%). From that reduction, 4 millions of US$ are redirected to the construction of new latrines (increasing the number of people attended from 22% to 38%), and 1 million is employed to hygiene promotion campaigns (expecting an increase of people practising appropriate hygienic practises from 19% to 27%).

Table 41 shows that allocation of resources in favour of sanitation and hygiene-related issues generates higher improvements in some of the SPI and HPI components, while decreasing the access to water. Far from argue the right policy to consider, this example pursued to present the possibility to generate different alternatives, under a same budget, in order to evaluate their impacts. In addition to this, this analysis "macro" should provide a first assessment to support decision-making. Ideally, same process might be done at district level as to design the most appropriate strategies for each location.

	Water Poverty Index					Sanitation Poverty Index				Hygiene Poverty Index				
	R	A	C	U	**WPI**	A	C	U	**SPI**	DW	PH	F	DH	**HPI**
Mean (WaSH)	0.66	0.49	0.52	0.65	0.52	0.42	0.73	0.49	0.51	0.63	0.38	0.38	0.53	0.49
Mean (SS)	0.66	0.48	0.52	0.65	0.52	0.44	0.73	0.52	0.53	0.65	0.39	0.40	0.53	0.50
Difference	-	*-0.01*	-	-	**-**	**0.02**	-	**0.03**	**0.02**	0.02	0.01	0.02	-	**0.01**
Note: In bold, positive improvement in favour of the simulated scenario (SS). In italics, negative difference.														

Table 41. Comparison between estimated results of the WaSH Programme (upper-line values) and the simulated scenario.

In this overall Section 5, the results presented by the ooBn were compared with the ones provided by the WaSH-PI. As showed, both WaSH-integrated approaches point out a same tendency of the values for each composite and component. Although slight differences were found, the proposed Decision Support System might be validated. Nevertheless, refinements should be provided by the participation of involved stakeholders in this sector and a further calibration should be done by uploading existing evidences.

A next step fell on the application of this instrument to assess the WaSH Programme launched by the Government of Kenya, which represents a multi-dimensional intervention aimed to increase the access to improved water, sanitation and hygiene in 22 of the 47 existing districts. Through the simulation of two scenarios; before and after WaSH Programme implementation, the impacts of the initiative at both total intervened area and district level were evaluated.

On the other hand, individual interventions for each dimension (water, sanitation and hygiene) were simulated. The objective was twofold. Firstly, it was pursued to unravel the impacts among the dimensions. Secondly, it was analysed the sensitivity of the ooBn when simulating alternative scenarios. In parallel, those impacts were quantified in terms of economical efforts.

Another step forward was taken by showing the flexibility of ooBn to conceptualise the problem backwards. This is, desirable impacts were targeted and related actions were economically estimated. It is thought that this possibility offers an interesting advantage for sectoral planning. However, as mentioned, due to its complexity, this exercise was done partially.

In brief, it has been shown how ooBn can accommodate data from different sources in order to evaluate the impacts of any related intervention. The possibility to simulate different scenarios, from a focused or integrated approach, offers the potential to assess their impacts and translate them into economical terms. In the same way, and as done ultimately, investment can be translated into specific actions and, therefore, related impacts might be assessed.

With all this in mind, it is concluded that this DSS represents an effective management tool to support decision-makers to formulate informed choices between alternative actions.

6. Conclusions and way forward

In this master thesis, an original approach to the water and sanitation sector was applied. As a starting point, a suitable framework (WaSH-PI) was selected, as it keeps water, sanitation and hygiene idiosyncrasies in focus. This is especially relevant since, in practice, WaSH-related responsibilities and interventions are assumed by different stakeholders and sanitation and hygiene suffer from the existence of water budgetary dominance, respectively.

Far from questioning the conceptual framework or carrying out a deep analysis of the WaSH-related problems at a particular location, this master thesis focus its attention on underlining the advantages of applying Bayesian networks as a decision support tool in the water and sanitation sector.

It has been demonstrated the potentiality of using an Object-oriented Bayesian network approach as an effective management tool to support decision makers to formulate informed choices between alternative actions.

On the one hand, key positive aspects can be summarized as follows:

i) In terms of conceptualisation, this DSS provides a holistic and transparent framework on which causal-effect decisions in WaSH planning and management can be based;

ii) In terms of use, ooBn offer the possibility to combine effectively a wide variety of information sources relevant to WaSH-related issues. Different sets of data from social, environmental, physical and economical domains have been used. In those cases where data were limited or nonexistent, it has been necessary to fall back on “expert opinion”.

iii) In terms of applicability, this tool is presented as a suitable one, since it permits to deal with data uncertainty in a transparent way and to explicitly represent it in the output, which is particularly important in data-scarce contexts;

iv) In terms of sectoral planning, ooBn enable decision makers to simulate and assess the effect of potential actions. In this way, it facilitates the identification of the interventions in which to direct their efforts for maximum impact;

v) In terms of robustness, the fact of populating the model with existing evidences of any conditioned event makes it especially robust, since extreme simulated scenarios and remarkable “disturbances” didn’t impact notably on the final results.

On the other hand, as presented, this tool requires non-free software and, to some extent, needs to be used by highly qualified people. This fact is considered a remarkable drawback as it hinders its wider implementation in rural low income regions, where resources are limited and stakeholders often lack capacities to profit from the model once developed.

Finally, some observations are listed below:

i) Effectiveness and reliability of this DSS remains elusive, since there is a lack of stakeholders involvement and participation, which represents a challenge and a benefit simultaneously. This engagement should be considered as a process, not a single activity at a point in time. Stakeholder engagement is essential to the development of the Bn, indeed it should be integral to it (Bromley 2005).

ii) As mentioned, results are based on existing evidences which provides the model with a notable level of robustness. However, when the impact of both medium and long-term interventions are to be assessed, these evidences need to be uploaded in order to calibrate the model, and so the sectoral strategy;

iii) Unless it was partially demonstrated the potential of Bn to be run inversely, this fact is presented as a remarkable advantage. Even more, when dealing with important investments, it might be useful to optimize the interventions in order to achieve the expected results. Existing technologies (i.e. genetic algorithms) could be a complementary tool to explore together with the Bn.

These three aspects suggest the way forward.

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