

## APPLICATION OF BAYESIAN NETWORKS TO ASSESS WATER POVERTY

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**Summary.** *The conventional approaches to water assessment are inappropriate for describing the increasing complexity of water issues. Instead, an integrated and holistic framework is required to capture the wide range of aspects which are influencing sustainable development of water resources. It is with this in mind that the Water Poverty Index (WPI) was created, as an interdisciplinary policy tool to assess water stress that links physical estimates of water availability with the socio-economic drivers of poverty. In parallel, in light of the investments envisaged for the next decade to reach the sector targets set by the Millennium Development Goals (MDGs), appropriate Decision Support Systems (DSS) are required to inform about the expected impacts to be achieved throughout these interventions. This would provide water managers with adequate information to define strategies that are efficient, effective, and sustainable. The paper explores the use of object oriented Bayesian networks (ooBn) as a valid approach for supporting decision making in water resource planning and management. On the basis of the WPI, a simple ooBn model has been designed and applied to reflect the main issues that determine access to safe water and improved sanitation.*

*A pilot case study is presented for the Turkana district, in Kenya, where the Government has launched a national program to meet sector targets set out in the MDGs. Main impacts of this initiative are evaluated and compared with respect to the present condition. The study concludes that this new approach is able to accommodate local conditions and represent an accurate reflection of the complexities of water issues. Such a tool helps decision-makers to assess the effects of sector-related development policies on the variables of the index, as well as to analyse different future scenarios.*

## 1 INTRODUCTION

In recent years, the provision of a reliable, sustained and safe water supply for people worldwide has become a top priority on the international agenda. To highlight concern, in 2000 the United Nations launch the Millennium Development Goals (MDGs), and set international targets for the water sector. In particular, Target 10 of Goal 7 explicitly deals with people who do not have access to safe drinking water and basic sanitation<sup>1</sup>. Nevertheless, for many developing countries the situation presents a huge challenge, and significant investments are envisaged for the next decade.

It is essential to be able to assess the impact achieved throughout these interventions to allow efficient and sound decision making. Appropriate indicators are thus needed to measure performance and allocate resources to deliver basic services where they are most needed. Up to date, the evaluation strategies have often been inefficient, with only a few aspects related to the water cycle being taken into consideration. In other words, traditional “access” indicators have not been able to provide accurate information for sector monitoring, nor they have properly assessed the extent to which water resources usage is sustainable in the long run.

Several issues impact the ability of people to access safe water and improved sanitation, which may be different in nature (physical, social, economic, ecological, etc.). An interdisciplinary approach is required to produce an integrated assessment of water scarcity, by linking physical estimates of water availability and the socio-economic factors which impact on access and use of this resource. The Water Poverty Index<sup>2</sup> (WPI) provides a suitable framework in this respect since it encompasses water resources availability, people’s ability to get and sustain access to water, to use this resource for productive purposes, and environmental factors which impact on the water supply to ecosystems.

Such an index should enable decisions to be made on a much wider basis, though a comprehensive Decision Support System (DSS) is required to properly collect data from many sources and integrate them to inform decisions. The methodology that has been developed in this study to model water poverty exploits the flexibility of Bayesian networks (Bns), a type of DSS based on the concept of conditional probability<sup>3</sup>. Bns are techniques that have gained a reputation of being helpful for simulating complex problems which involve uncertain knowledge<sup>4</sup>. In the water resource context, where many variables are highly interlinked and uncertainty plays a key role<sup>5,6</sup>, they have been increasingly applied as an aid to decision-making<sup>4,5,6,7,8,9</sup>. The paper particularly focuses on the construction of a model made up of traditional and object oriented Bayesian Networks (ooBn). Such approach allows complex domains to be described in terms of interlinked objects, and thus provides an appropriate framework to simultaneously deal with the main components of the Water Poverty Index (Resources, Access, Capacity, Use and Environment).

This case study was developed for the Turkana District, in Kenya, where the Government has launched a programme to improve the access to sustained water supplies, sanitation infrastructure and hygiene (WASH) for the rural population in 22 districts. Taking the original WPI definition as a starting point, the objective of this article is to demonstrate the usefulness of Bns to inform about the foreseen impact of this initiative. It is shown that these networks are able to accommodate the complexities of water issues, and that Bns have the potential for

wider implementation as policy tools in the context of water resources management. The paper is structured in the following way. After the present introduction, Section 2 describes the context of the study, including the theoretical basis and the regional setting. Section 3 goes through the process of network construction. An assessment of the WASH Programme applying developed networks is presented in Section 4. Major findings are highlighted in Section 5 to conclude the study.

## 2 CONTEXT OF THE STUDY

In the light of implementation of the Programme, the issue of prioritization becomes crucial in determining the most cost-effective strategy. Water 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 Bns.

This paper first adopts the WPI framework because of its comprehensiveness to integrate all relevant water 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 Programme implementation.

In this section, the context of the study is summarized. It introduces the framework of the index, as well as the theoretical background of Bns. Finally, the regional setting of the case study is briefly outlined.

### 2.1 The Water Poverty Index

The Water Poverty Index, introduced by Sullivan<sup>2</sup>, is a holistic tool that integrates the key issues relating to water resources, aimed at identifying the ability of countries or regions to address their water supply needs. The development of such an index should enable decision makers to identify and track the physical, economic and social drivers which link water and poverty<sup>2</sup>. Its theoretical framework distinguishes a number of aspects which reflect major preoccupations in low-income countries related to the provision of water: physical availability of water resources (R), extent of access to water (A), people's ability and capacity for sustaining access (C), ways in which water is used for different purposes (U), and the environmental factors that impact on the ecology which water sustains (E).

Numerically, the WPI<sup>10</sup> is given by:

$$WPI = \frac{w_r R + w_a A + w_c C + w_u U + w_e E}{w_r + w_a + w_c + w_u + w_e} \quad (1)$$

where WPI is the index value for a particular location, and w is the weight applied to each of the components. Different weighting systems can be employed to indicate the importance

of each variable. Nevertheless, equal indicator weights are often preferred, since there is no evidence that it be otherwise<sup>10</sup>. Likewise, use of an additive structure appears to make the index more transparent and acceptable to different stakeholders than other aggregation functions (e.g. geometric, multi-criteria ...).

## 2.2 Bayesian Networks

A Bayesian network (Bn) is a type of decision support system based on probability theory using Bayes' rule. Bns are directed acyclic graphs that exploit the duality between an interaction graph and a probability model<sup>5</sup>. The graphical structure provides a visual representation of the logical relationship between variables, while conditional probabilities quantifies this relationship and are thus required to fully run the network. They are made up of three different elements<sup>3</sup>; (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 express cause-effect relationships among them, 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<sup>5</sup>. As more data or knowledge is accessed, the relevant CPTs might be updated to reflect the improved data set<sup>5,6</sup>.

In this respect, Bns are powerful for incorporating data and knowledge from different sources and domains<sup>5,6,7</sup>, 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<sup>6,7</sup>. In those situations involving uncertain knowledge or when a large number of factors that are linked together need to be taken into consideration, Bns might be used to support decision-making<sup>6</sup>. Again, this makes this technique an adequate policy tool in the field of water resource management, where dealing with complex environmental systems is inevitable, and since data are often uncertain and scarce.

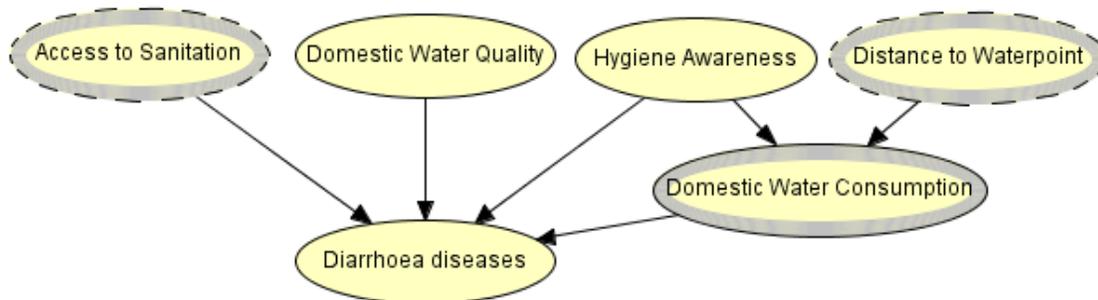


Figure 1: Simplified OOBN for assessing incidence of diarrhoea, containing “Access to Sanitation” and “Distance to Waterpoint” as input nodes and “Domestic Water Consumption” as an output node.

Nevertheless, a conventional Bn is unable to receive or transmit information from outside

the system<sup>8</sup>. Instead, an ooBn model provides a suitable framework that allows different networks to be linked together. 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. 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, as shown in Figure 1.

### 2.3 Regional setting

The Turkana district is the largest in Kenya. It is also one of the poorest, with frequent droughts and famines, covering 70,720 km<sup>2</sup> of some of the most arid parts of the country. Turkana is located in the Rift Valley Province, and borders on Uganda to the west, Sudan to the north west, and Ethiopia to the north east. The district, whose administrative headquarters is at Lodwar, is divided into 17 administrative divisions (see Figure 2). The population density in this vast district is low, the total population being estimated at 450,860 (1999 National Census).

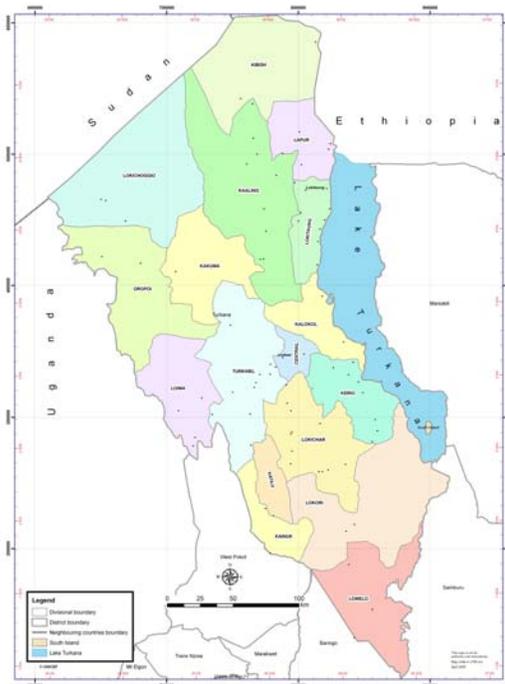


Figure 2: Administrative boundaries of Turkana district<sup>12</sup>



Figure 3: Map of Kenya showing the Programme districts.

The main strategic challenges affecting water provision in the district include poor access to basic services, inadequate quality of water, weak control and regulation of water use, dam

silting, lack of maintenance of water supply facilities, and inadequate rain water harvesting<sup>11</sup>. In particular, and based on data at the national scale<sup>12</sup>, only 31% of the population living in rural areas are using improved sources for drinking water, while 36% of people have access to adequate sanitation facilities. As a consequence, the prevalence of water-related disease is increasing, contributing to higher rates of mortality among children under five years old. This currently stands at 115 per 1,000 children<sup>12</sup>, of which diarrhoeal diseases account for about 20% of cases. A priority concern is thus to address the major underlying causes of all these water-borne diseases; i.e. water quantity is insufficient and it is often unsafe to drink and to prepare food; the majority of households do not have toilet facilities; and primary caregivers do not have adequate hygienic practices.

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 (2006 – 2011)”. This initiative is aimed at increasing the access to improved water, sanitation and hygiene in 22 districts (see Figure 3), contributing to the achievement of the sector-related Millennium Development Goals.

As a pilot, this study focuses on one of these 22 districts, Turkana

### 3 DEVELOPMENT OF NETWORKS

This section deals with the development of an ooBn to be used as a decision support tool, targeting the water poor at a local scale. In particular, the aim is to build a network to help assess the impact of the implementation of the WASH Kenyan Programme on water poverty at the community scale. To this end, a commercial software package produced by HUGIN has been used for Bn construction.

The method of network construction involves three key steps.

- i. *Identification of the variables relevant to the problem* and definition of key linkages among them. To assess the level of water poverty, the network has been divided into five sub-networks to represent the five components of the WPI. A large number of variables (81) have been identified and classified based on their nature<sup>3</sup>: “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); and “Controlling Factors” (in orange) are other variables which somehow influence the system but cannot be controlled (Table 1).
- ii. *Data collection for the probability tables that lie behind the variables.* A key part of the process is to make sure that the tables constructed for each variable are 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. In this paper, data used have been generated through a combination of relevant literature review and two major information sources: (i) the ‘Water, Schools and Health Management Information System (MIS) for the Turkana District’<sup>12</sup>,

which was developed as a comprehensive record of all water sources available in the district; and (ii) the main report of the Programme of Cooperation “Acceleration of Water Supply and Sanitation towards Reaching Kenya’s Millennium Development Goals (2006 – 2011)”<sup>13</sup>. 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.

Sub-network	No. of Variables	Category			
		Objective	Interventions	Interm fact.	Control fact.
Resources	13 (4)	3 (1)	1 (1)	5 (1)	4 (1)
Access	21	3	2	13	3
Capacity	18 (1)	3	5	10	(1)
Use	9 (3)	4 (2)	2	3 (1)	---
Environment	20 (3)	3 (1)	2	14 (2)	1
Total	81	16	12	45	8

Note: In brackets, number of input nodes.

Table 1: Classification of variables at sub-network level

- iii. *Assignment of the states for all variables and completion of the conditional probability tables (CPTs).* Once the variables have been defined and grouped, their states and probabilities are assigned using available data or expert knowledge. The 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. The complexity and size of the CPTs depends on the number of parents and the number of states the respective variable has<sup>3</sup>. It is, therefore, advisable to construct the network with a limited number of parents and states; in this way the CPTs become much more manageable.

Explaining the meaning of each individual variable is not feasible, therefore, only a broad outline of the sub-networks follows.

### 3.1 Resources

Water resources in Kenya have been diminishing because of environmental degradation, lack of water conservation, and spread of pollution sources: diffuse pollution sources such as silting and agrochemicals, and point pollution sources including industrial wastewater effluents, solid wastes, and domestic sewage<sup>14</sup>. But the most influential factor has been the variation in climate<sup>13</sup>.

Turkana district is particularly prone to frequent droughts. It receives an annual average rainfall of 120 mm, and the district is classified as arid<sup>11</sup>. The rainfall pattern and distribution is erratic both in time and space, although the probability of rainfall is the highest during the long rainy season between April and August.

The district's main sources of water are ephemeral rivers, Lake Turkana, underground water, springs, dams and pans. This resource is mainly exploited via gravity (basin irrigation) and direct access for domestic and livestock water supply<sup>12</sup>. Above all, the population relies on river and shallow wells for water, especially the shallow groundwater aquifer associated with dry riverbeds<sup>14</sup>. The district has 4 main seasonal rivers (Turkwel, Kerio, Suguta and Tarach), though the most important tributary of Lake Turkana is the River Omo, which enters the lake from Ethiopia and contributes more than 90% of the total inflow. The lake has no outlet, and water is lost mainly by evaporation. Very little hydrogeological data is available for effective evaluation in the region, and groundwater recharge zones and amount of groundwater recharge to the lake are largely unknown<sup>14,15</sup>. However, because of land degradation and the increasing number of settlements, it is likely that groundwater recharge has, to some extent, decreased<sup>14</sup>. There is thus a need to establish the extent and volume of groundwater resources and to initiate its sustainable development as a source of potable water in the region

The freshwater resources are critical for the livelihoods of the pastoralists and agro-pastoralists in this largely arid district. With the very low rainfall in the region, food security is inextricably linked to the water resources. However, the rate of abstraction is currently unsustainable and freshwater shortage is likely to become more acute<sup>14</sup>. There are thus a number of key strategic challenges in managing water resources that are constraining the capacity of the people to build a sustainable livelihood system around livestock<sup>11</sup>. At least, communities need to be empowered to manage existing water facilities responsibly; and sources should be protected from domestic and livestock contamination.

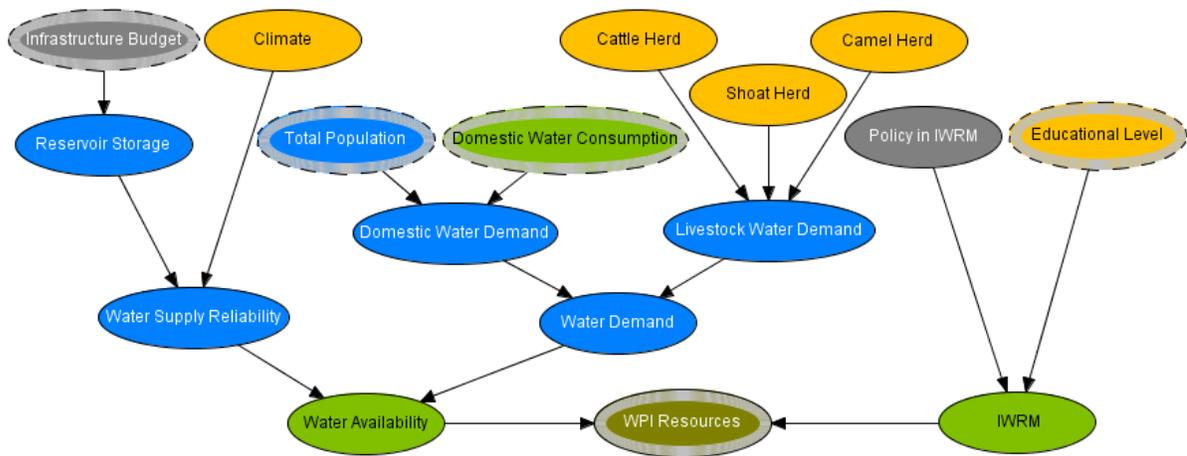


Figure 4: The Resources sub-network

### ***The Resources sub-network***

The ‘Resources’ network measures availability of water resources (Figure 4). It is based in the context of diminishing water availability as a result of inadequate management of water

resources on the supply side, and increasing use of water as a function of population growth and local livelihoods on the demand side.

In this respect, a set of variables determine water quantity as a balance between water demand and availability. 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. Hydrogeological data are basically non-existent and groundwater recharges unknown. Information sources employed to assess these nodes have thus been qualitative.

At the same time, studies are required to quantitatively determine the effects of reservoirs construction on freshwater shortages and on water supply reliability. As distinct from this supply-side focus on developing the “water resource” by investing in infrastructure, Integrated Water Resources Management (IWRM) emphasizes the need to also embrace demand-side management, so that the needs of all users are met, while at the same time maintaining a healthy environment. On the whole the ability to make headway towards IWRM is currently limited.

### **3.2 Access**

In the Turkana District, lack of access to safe water and adequate sanitation remains particularly acute. It is estimated that only 28% of households have access to potable water, while proper sanitation facilities are basically non-existent<sup>14</sup>. Moreover, about 20-30 per cent of the community-managed water supplies developed over the past 20 years are no longer functional<sup>13</sup>. This high rate of malfunction is caused by poor access to a reliable supply chain for spare parts; a lack of capability of institutions to help the recipient communities manage the services; poor governance at the community level; and a reduced ability of the population to pay for water. Although construction of new schemes is required to increase coverage, the Programme also needs to focus on building up recipient capacity to maintain them.

Because water supply and sanitation are not well-defined interventions, but can be provided at various levels of service with varying benefits and different costs, a consensus on a definition of “reasonable access to safe water and improved sanitation” is required.

With regard to provision of water, and since most consumers are unable to tell whether their water supply is safe or not, an “improved” water supply<sup>16</sup> is defined in terms of the type of technology being used. As a rule, “improved” water supplies could be expected to provide water of better quality and with greater convenience than traditional “unimproved” sources<sup>17</sup>. The access component is usually defined by setting the amount of time spent fetching water or the maximum distance from source to the user’s dwelling, less than one kilometre being broadly accepted as a reasonable distance

In much the same way as with water supply, care is needed to define an acceptable form of excreta disposal. A wide range of technologies is used, particularly for situations where low-cost solutions are required. Relevant research, conducted elsewhere<sup>17</sup>, has concluded that all types of sanitation facility, no matter how basic, can be operated hygienically. As a result, the Global Assessment Report<sup>16</sup> chose not to distinguish between sanitation technologies; instead, all of them are considered as providing adequate access to sanitation as long as they are

private or shared (but not public) and hygienically separate human faeces from human contact.

**The Access sub-network**

Taking previous definitions as a starting point, this sub-network assesses whether or not people have access to improved water supplies and sanitation (Figure 5).

As a key measure of accessibility a set of variables are used to determine the reduction of time invested in securing water after the Programme completion. However, no data was collected on water user fees, which 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. Therefore, if the project is aimed at poverty eradication, the “Access” variable would need to target poor people living in rural areas that currently do not use safe drinking water and/or sanitation facilities and do not practice appropriate hygiene.

The sanitation component considers the number of people to be served by the project.

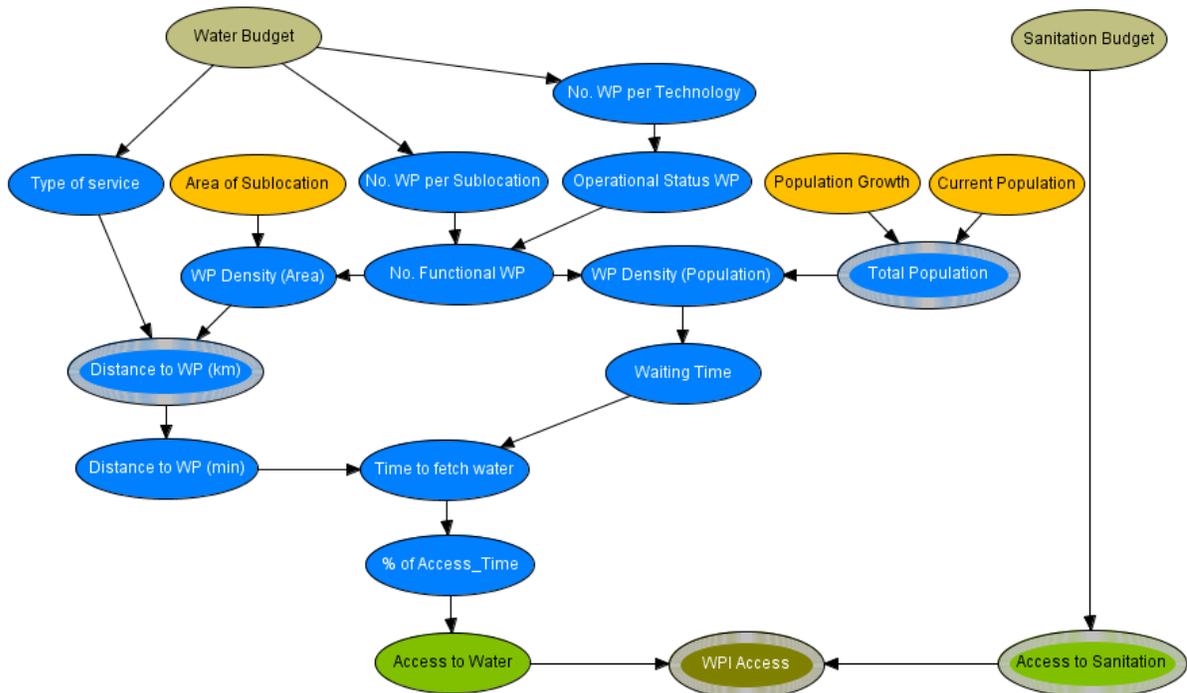


Figure 5: The Access sub-network

**3.3 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<sup>18</sup>. The underlying theory is that meaningful and

rapid development is best achieved through a decentralization process<sup>19</sup>; 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 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<sup>20,21,22,23</sup>. 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 Providers (WSPs) 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<sup>13</sup> that waterpoints 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 Turkana district. Such gaps are currently filled through sourcing from neighbouring districts or from Nairobi. 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 Capacity sub-network**

This network (Figure 6) aims to represent all key variables that determine to what extent the decentralization process is to be implemented throughout the Programme.

The first group of nodes focuses on the institutional framework required to properly manage the services. Integral to this 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. . However, no reliable data relating to this aspect was available so this information has been omitted from the model. Another group of variables determines the status of the supply of equipment and spare parts in the local markets, as well as the private sector skills and capacities. Both aspects are required to properly operate and maintain the facilities once the intervention is completed.

Finally, it should be noted that the “output” node “WPI Capacity” is likely to be related to the long-term functionality of the water schemes (in the Access sub-network). However, this variable appears itself as an “objective” node, and therefore this causal relationship has not been considered in order to avoid redundancy and double-counting, which might bias the result.

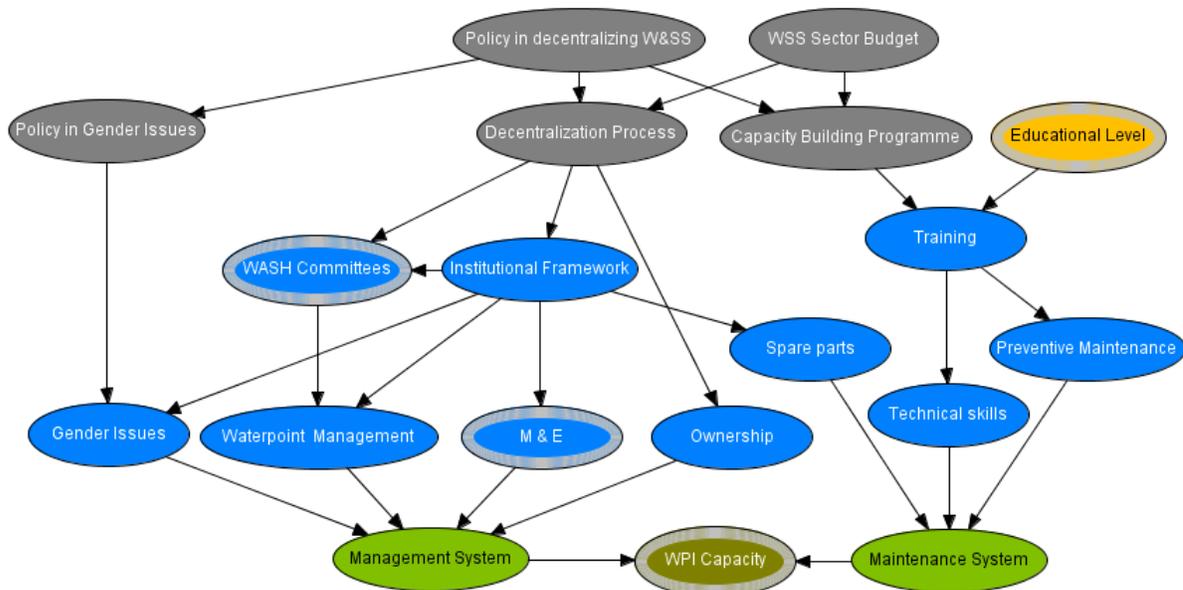


Figure 6: The Capacity sub-network

**3.4 Use**

The people in the area are mainly pastoralists, and to a lesser extent, agro-pastoralists. Therefore, although the primary purpose for investment should be to increase the use of safe domestic water for households, the promotion of low cost water saving technologies that can be used to increase food production is also essential.

In agro-pastoralist societies, small-scale irrigation and livestock watering are key

components for sustaining livelihoods. These activities require an adequate water supply.

Equally important, 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. In this region, it is expected that more than 25% of the population are affected by bacterial-related gastroenteric disorders<sup>14</sup>. 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. 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.

In this respect, 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<sup>24,25,26,27</sup>. In particular, Cairncross and Feachem<sup>26</sup> 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 waterpoint 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<sup>26</sup>.

### ***The Use sub-network***

This variable captures the use communities make of the water, and tries to highlight that water availability for growing food (agriculture and livestock) is as important as domestic consumption (Figure 8). The network identifies two potential types of action for promoting an adequate water usage: hygiene awareness-education campaigns, and implementation of low cost water saving technologies.

First, a set of nodes determine reductions in diarrhoeal diseases due to improvements in water and sanitation infrastructure and hygiene education. It indicates that water may become contaminated by poor collection, transportation and handling practices; as people collect it from a source 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<sup>28</sup>, so its promotion as an effective practise appears to be premature. In any event, since accurate health data is lacking, a comprehensive literature review<sup>24,25</sup> has provided an adequate starting point to report median reduction in morbidity from each type of intervention.

Second, the amounts of water required for purposes other than domestic needs are often larger, and this can lead to competition between uses. Reports of conflicts over water sources are included as a variable in this respect.

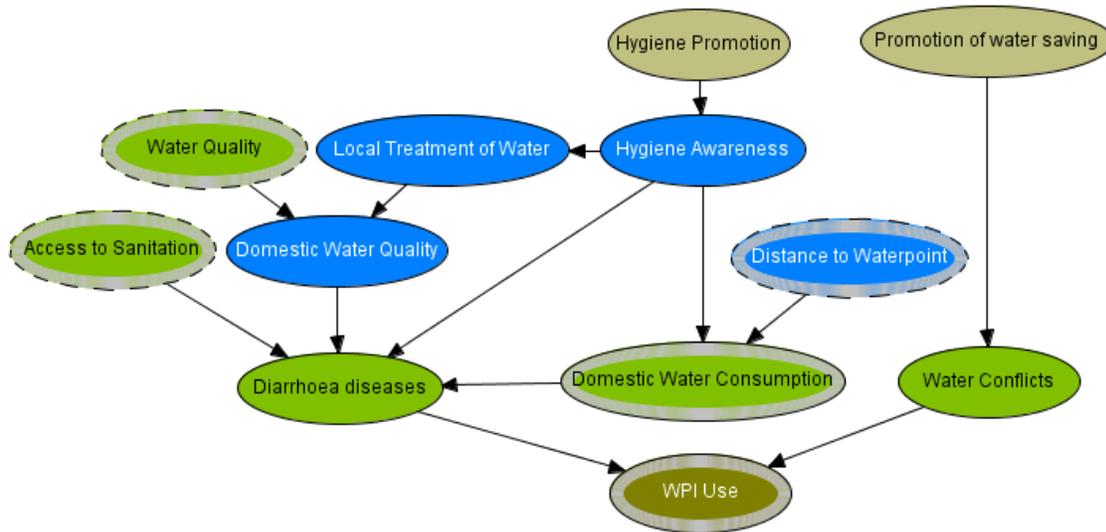


Figure 8: The Use sub-network

### 3.5 Environment

Improvements in water supplies should not lead to environmental damage. A primary concern with environmental degradation is its likely impact on water resources, especially on water quality.

The Lake Turkana water itself is not suitable for drinking due to its moderate salinity (2.5‰), high alkalinity (pH = 9.2) and total dissolved solids concentration<sup>15</sup>, but as previously mentioned, the affluent river waters and shallow wells along the rivers are being used as sources of potable water. At present, there is no evidence to show that microbiological and chemical pollution, solid wastes, and spills are of any threat to the lake and its rivers<sup>14</sup>; since there is basically no industrial, large scale agricultural, or other type of development that can significantly contribute to contamination of the water bodies. On the other hand, populations close to the riverbanks are likely to pollute the waters to not inconsiderable levels, thus rendering the freshwater shortage more acute because of its reduced quality. In particular, contamination of point sources may occur because of inadequate sanitary protection measures due to poor design, siting, construction or lack of maintenance<sup>29</sup>. Therefore, a range of measures might be in place to protect the source from becoming contaminated, not only those in the immediate area of the waterpoint but also broader protection measures. Besides source protection, and since water quality may change very rapidly over time and short distances, appropriate routine monitoring programmes are also required.

The Water Resources Management Authority (WMRA) is responsible for the protection of the water resources, and an effective sector coordination mechanism should be in place to

strengthen collaboration with the National Environment Management Authority (NEMA), which has the legal mandate for environmental protection. In short, potential environmental impacts that could arise include (i) abovementioned contamination of water bodies; (ii) land degradation, increased erosion rates and deforestation; (iii) conflicts over grazing; (iv) intense cultivation which require application of fertilisers and pesticides; and (v) proliferation of human settlements. Although there is no direct information to assess previous impacts in the district, it is known that they all will lead, to some extent, to the depletion of natural water supplies (both surface and groundwater), with evident adverse consequences.

Finally, construction of dams in the region may have impacted negatively on the livelihoods of downstream river users and the lake ecosystem, through increased freshwater shortage and lowered lake levels<sup>14</sup>. Studies are, however, required to quantitatively determine the environmental effects of dam construction<sup>14</sup>.

### *The Environment sub-network*

The network combines a number of environmental indicators which not only cover water quality, but also variables that are likely to impact on ecological integrity (Figure 9).

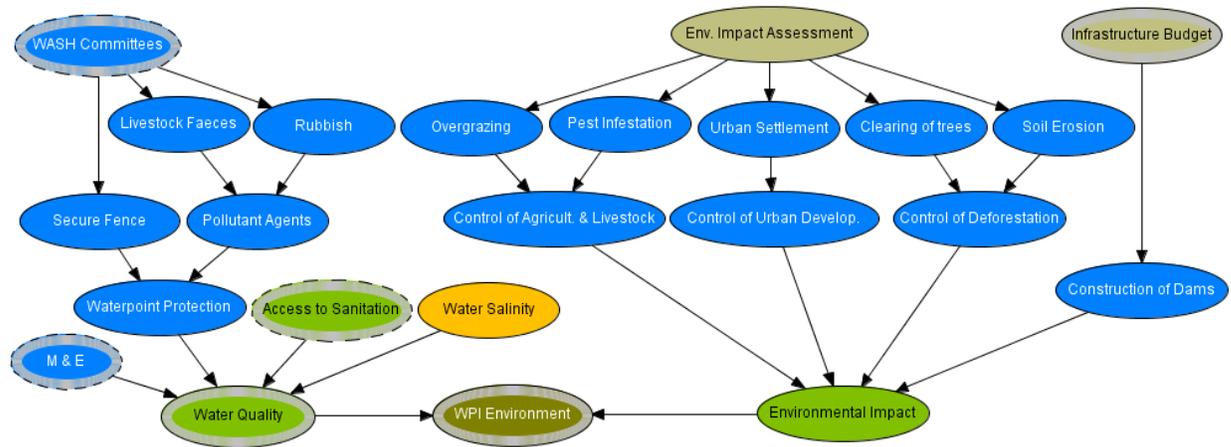


Figure 9: The Environment sub-network

This sub-index is thus calculated on the basis of an average of two different nodes: (i) water quality, as an important factor influencing its availability; and (ii) an environmental impact assessment, which considers all potential environmental impacts on water resources.

In terms of water quality, it should be noted that no data was collected on microbiological quality and other biochemical parameters, and information was obtained through qualitative questionnaires. Further refinements to the network include the provision of sound data in this regard. The second subgroup of variables deals with major potential environmental hazards.

### 3.6 The Water Poverty Index, through an object oriented Bayesian network

To represent the theoretical framework of the water poverty index an ooBn approach has been used, exploiting the flexibility of Bns.

In this respect, in previous sections each variable of the original index has been presented as a separate sub-network. In these five sub-networks, the “objective” variable appears as an output node, but also as an input node in an additional master network that has been developed to integrate all the index variables. These “instance” nodes thus enable the link between five sub-networks and the master network. At the same time, simple causal relations are not very conducive to a good understanding of the system. It is believed that some variables are relevant for multiple sub-networks, and to accommodate them in one single sub-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 10.

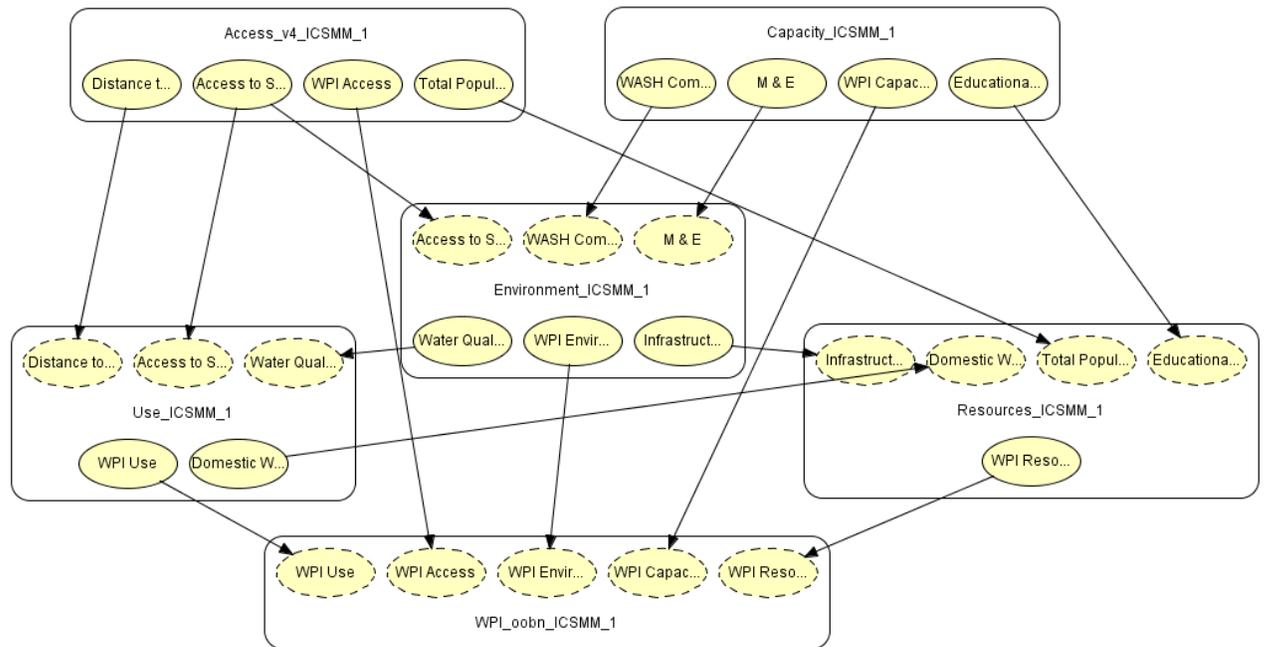


Figure 10: Scheme of the ooBn master network

It can be seen from the graph that any refinement in a variable of any sub-network will result in a chain reaction of impacts on all the linked variables, affecting the outputs of the whole system. In consequence, a major advantage of this tool is that it can easily predict the impact of a number of potential interventions on all interrelated factors; and therefore to identify which action, or combination of actions, will produce desired results appears straightforward.

In terms of method, the aggregation function employed in index construction is the

summation of the equally weighted sub-indices (Resources, Access, Capacity, Use and Environment), as outlined in Section 2. Within a network, links between variables are not restricted to probability tables, and they can also be specified through a standard mathematical expression. Thus, and equal to the original index, the final “objective” node “*Water Poverty Index*” is assessed through the unweighted average of the five parent variables.

The resulting WPI values fell in the range 0 to 1, where the highest value 1 denotes best situation (i.e. lowest level of water poverty), while 0 is the worst.

#### **4 ASSESSMENT OF THE IMPACT OF THE WASH PROGRAMME: RESULTS AND DISCUSSION**

The task of evaluating the overall impact of a WASH intervention on water poverty is a daunting task. It goes beyond simply determining an objective number of beneficiaries or assessing a defined set of verifiable indicators. 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 has been adopted for this purpose.

The results shown in this section represent a first attempt of the development and application of an ooBn to assess the water poverty index at local scale. Clearly, rigorous checking to prove that the index values are coherent with the true degree of water poverty remains elusive. Rather, such a tool might serve to assist with a preliminary evaluation of the targets set by the WASH Programme.

Two different scenarios have been simulated. The first scenario is assumed to be described by the current situation, where no intervention has been undertaken; whereas the second scenario adopts the project approach. In accordance with the Programme strategy, the set of actions to be implemented have been represented in the networks as “intervention” variables (listed in Table 2). It is by acting on these nodes that the software has simulated both scenarios.

The impacts of the WASH initiative have been determined and compared with respect to the present condition, and such changes are presented in Figure 11. According to both graphs, the intervention would produce a positive impact on overall water poverty, since values of the index slightly improve after the project completion. However, the index provides a starting point for analysis. An accurate focus on the five variables might help to direct attention to those water sector needs that require special policy attention.

For example, and in accordance with Figure 11a, aspects requiring urgent intervention are those related to the “Use” components, though “Access” and “Capacity” variables are also far from being adequate. If this situation is compared to that represented in Figure 11b, it can be seen that the Programme primarily impacts on the “Use” sub-network, while it also improves to different extent the rest of variables.

A more detailed description of achieved results at sub-network level follows.

Sub-network	Variable	States	No Intervention	WASH Programme
Resources	Policy in IWRM	Non-existence of policies to promote IWRM	1	0.5
		Existence of policies to promote IWRM	0	0.5
Access	Water Budget	No Intervention	1	0
		Rehabilitation	0	0
		New Infrastructure	0	0
		Rehab. + New Infrastructure	0	1
	Sanitation Budget	No Intervention	1	0
		Intervention – Poor	0	1
		Intervention – Adequate	0	0
		Intervention – Universal Programme	0	0
Capacity	Policy in decentralizing W&SS services	Non-existence of policies to decentralize services	0	0
		Existence of policies to decentralize services	1	1
	WSS Sector Budget	Non-existence of budget to decentralize services	1	0.5
		Existence of adequate budget to decentralize services	0	0.5
Use	Hygiene Promotion	Non-existence of hygiene promotion campaigns	1	0
		Existence of hygiene promotion campaigns	0	1
	Promotion of water saving technologies	Low cost water saving technologies are not promoted	1	0.5
		Promotion of low cost water saving technologies	0	0.5
Environment	Environmental Impact Assessment (EIA)	No EIA + No mitigation measures to minimize environmental impacts	1	0.5
		EIA + Mitigation measures to minimize environmental impacts	0	0.5
	Infrastructure Budget	Low	1	0.5
		Low – Medium	0	0.5
		Medium – High	0	0
		High	0	0

Table 2: Conditional Probability Tables of the “intervention” variables in two simulated scenarios

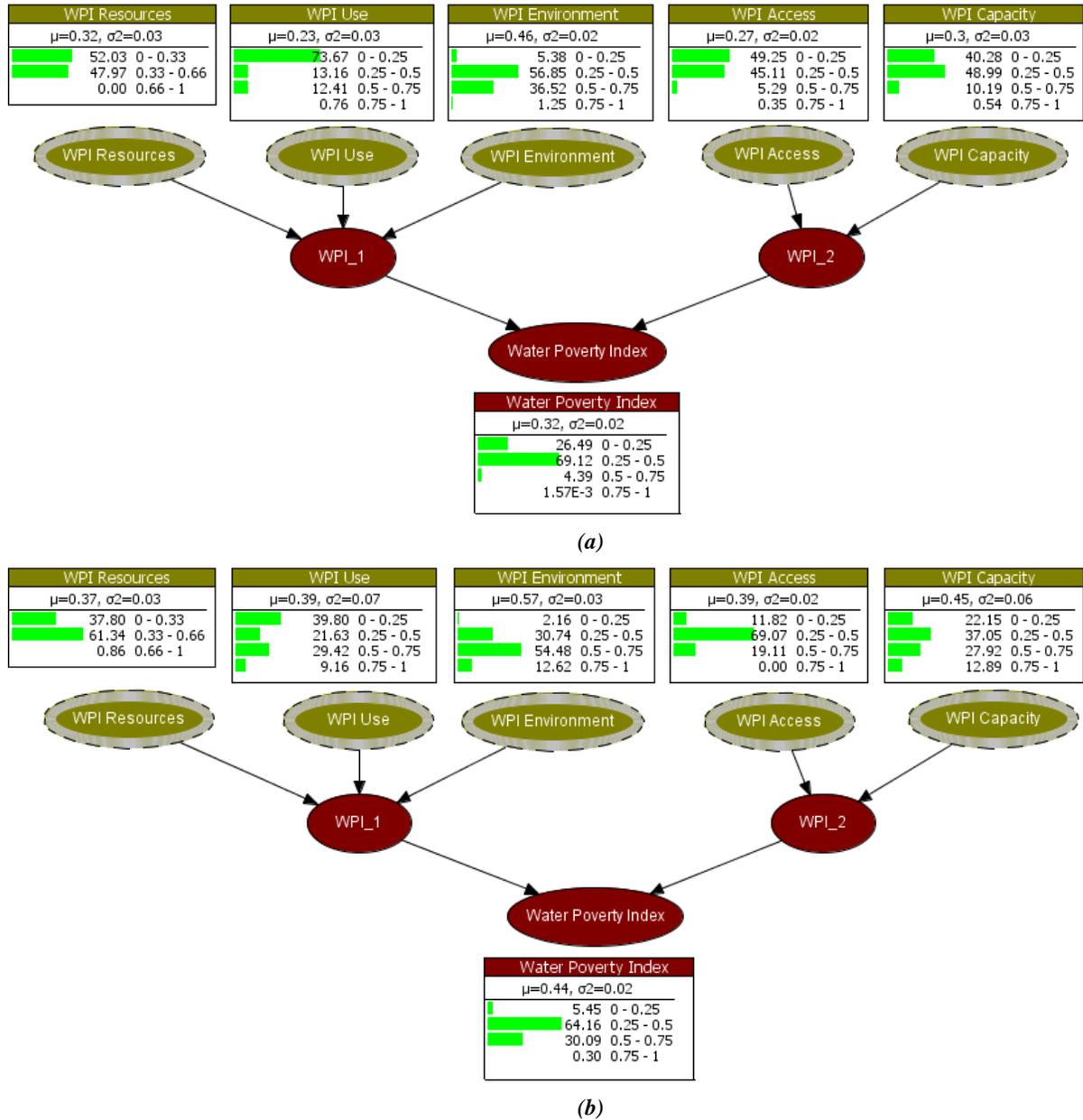


Figure 11: Final WPI Values: (a) No Intervention; (b) WASH Programme

#### 4.1 Improving water resources management

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.

It can be seen in Figure 11 that the “Resources” component slightly improves after project completion. However, the freshwater shortage still remains a priority concern for sustaining the livelihoods in the district.

#### **4.2 Constructing new infrastructure**

The rural water supply component of the intervention includes in the Turkana District the development of water sources for new users (32,500 beneficiaries) currently unserved, and the rehabilitation of existing dysfunctional water systems that will be used by additional 42,000 people<sup>13</sup>. 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). The promotion of household sanitation will be closely linked to the provision of water facilities and to promotion of hygiene. However, Government allocation and expenditure for environmental health is very low compared to expenditures for curative health. Sanitation and hygiene promotion therefore enjoys a very low profile. The implementation strategy relies on a competitive marketing approach, and the target is to ensure at least 23,320 households properly using a toilet at home<sup>13</sup>.

For the “Access” component, and contrary to what might be expected, the project investment is unlikely to meet the MDG water and sanitation targets. According to Figure 11b, it is estimated that more than half of the rural population still do not have access to safe drinking water and basic sanitation after the Programme completion.

#### **4.3 Building up recipient capacity**

Capacity to manage water facilities is required both at local and regional scale, and a major challenge is thus to address the existing gap in institutional performance. 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.

It is concluded from the results obtained that the institutional framework to aid communities to manage water facilities is far from adequate; there is still room for improvement in the majority of communities in terms of capacity building and institutional support.

#### **4.4 Promoting hygiene**

Hygiene education and promotion is expected to be a core activity within the Programme.

It will consist of two different components: promotion of behavioural changes and promotion of appropriate technology. In the same way as with sanitation, the target is to cover 23,320 households through direct marketing, though larger numbers are likely to be reached by mass marketing<sup>13</sup> (e.g. radio, local newspapers and promotional campaigns). At the end of the promotion, communities should have a good level of understanding of the link between poor hygiene and diseases.

At the same time, the project will foster hygienic handling of water as well as point-of-use treatment. 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. Technologies for treatment at the point of use will include solar disinfection, filtration and chlorination.

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 area.

The results depicted in Figure 11 reveal that major impact after project completion is related to the “Use” component. This highlights that hygiene promotion might be a true cost-effective intervention.

#### **4.5 Protecting the environment**

Preservation of the environmental integrity appears crucial. In this respect, it is the NEMA who has the legal commitment to protect and maintain the environment. Its regulations require EIAs to be carried out before approval of any major water projects; with the aim of minimizing potential environmental impacts. This clearly affects all the investments to be implemented throughout the Programme.

In parallel, the WMRA is responsible for the adequate management of the water bodies. As a key activity, a drinking water surveillance programme is to be developed for continuous water quality monitoring.

The “Environment” variable exhibited the highest scores; results show that promoting EIAs would allow the maintenance of the environment. On the other hand, more efforts are required to guarantee safe water for domestic consumption.

### **5 CONCLUSIONS**

In this paper we have demonstrated the relevance of the use of an ooBn approach as an effective management tool to aid policy makers to make informed choices between alternative actions. The main goal was not a deep analysis of water problems at a particular location through the water poverty index, as this is being published elsewhere<sup>30</sup>. Instead, this case study is aimed at underlining the advantages of applying Bayesian networks as a decision support tool in the water sector. Key aspects can be summarized as follows:

- This tool is effective in combining the wide variety of information sources relevant to water issues. Different sets of data from economic, environmental, physical and social domains have been used. In those cases where data were limited or non-

- existent, it has been necessary to fall back on “expert opinion”.
- Uncertainty of the data can be dealt with in a transparent way and be explicitly represented in the output, which is particularly important in data-scarce contexts.
  - The model provides a transparent and holistic framework on which decisions in water planning and management can be based.
  - To assess the behaviour of the model when a number of potential actions are simulated is straightforward. Therefore, Bns enable policy planners to easily identify the type of intervention in which to direct their efforts for maximum impact.

In contrast, a major drawback is that this tool requires non-free software that needs to be used by highly qualified people. This clearly 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.

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