

Understanding Rural Water Services as a Complex System: An assessment of key factors as potential leverage points for improved service sustainability

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Table S1. Demographic context information; Descriptive characteristics of rural water service delivery coverage, functionality, schemes and management for each context where the factor mapping workshops were conducted

	South Ari Woreda, Ethiopia	Mille Woreda, Ethiopia	Kabarole District, Uganda	Kamuli District, Uganda
Population	279,574	117,960	486,319	469,236
Water access	26%	23%	73 %	75%
Functionality	69%	87%	84%	88%
	n=348	n=31	n=1,577	n= 1,300
Water schemes	Hand pumps (34%), motorized wells (11%), Spring (55%)	Hand pump (48%), motorized wells (45%), Shallow Hand-dug wells (6%)	Springs (495), Shallow wells (631), Deep Boreholes (64), Pipe stands (386)	Springs (21), Shallow Wells (487), Deep Wells (792)
Management Schemes	Community Mgmt, Local Utilities	Community Mgmt, Local Utilities	Community Mgmt, Local Utilities, Private Sector	Community Mgmt, Local Utilities, Private Sector
Source	IRC SWS Baseline Report (2018)		Uganda National Water Sector Report (2016), Uganda National Census (2014)	

Table S2. Matrix of indirect influences (Kamuli Example); calculated from three iterations of matrix multiplication of Kamuli cross-impact matrix. Each cell contains the potential indirect strength of influence from the factor in the row onto the factor in the respective column.

	Water User Committee	Mechanics	User Fees	Political Support	Water Source By-laws	Monitoring	Spare Parts	Water Users	Service Sustainability
Water User Committee		9780	10702	4247	8820	8056	11151	9710	11740
Mechanics	5899		6807	2706	5607	5028	7025	6121	7305
Water User Fees	8087	8493		3674	7740	7022	9739	8372	10132
Political Support	6628	7019	7648		6302	5701	7952	6924	8332
Water Source By-laws	8251	8827	9478	3797		7114	10049	8726	10336
Monitoring	5583	5900	6455	2561	5385		6829	5904	7175
Spare Parts	6739	7210	7690	3100	6414	5756		7156	8394
Water Users	9851	10500	11370	4545	9364	8452	11851		12404
Service Sustainability	9501	10029	11020	4369	9106	8348	11555	10030	

Table S3. Names and definitions of factors for each context as proposed by workshop participants with common factor category name for affinity grouping

Context	Original Name	Definition	Common Factor Category	
Kabaroole	Community Ownership	Sense of responsibility, participation and involvement with community water point	Community	
	Coordination	Mechanisms and platforms bring stakeholders together, to share information, working collaboratively with particular attention to local government & CSOs	Coordination	
	Financing	Funds available through government transfers & grants (district level), tariffs & taxes AND Community Capital Contributions (CCC) for water services	Financing	
	Technology	Physical, functional infrastructure system(s) that are in place to reliably deliver clean water	Hardware	
	Local Government Capacity	Skills and knowledge needed to execute duties of position; human resource capacity	Local Capacity	
	O&M	Repairs, servicing, rehabilitation, correct use and operation	O&M	
	Political	The influence, planning, decisions making and actions of local lawmakers; district and local councilors	Politics	
	Private Sector Involvement	Organizations that supply materials and financing for water point construction, maintenance and rehabilitation. Includes HPMA's, contractors, NGOs, financial institutions & hardware dealers	Private Sector	
	Water Resource Management	Planning, use allocation, information sharing around policies for protection of local watershed and environmental resources	Water Resource Management	
Kamuli	Spare parts	Durable, availability, quality and affordable	Hardware	
	Mechanics	Mechanics are reliable, trained, equipped, accessible and trustworthy	Mechanics	
	Supervision + Monitoring	Checklist followed by technical group	Monitoring	
	Political Presence + Support	Politicians putting in place enabling policies	Politics	
	Water Source By-laws	Approved by subcounty authorities, enacted by the community	Regulations	
	Water user committee	A fully constituted, trained and functional committee	User Committees	
	Water user fees	An agreed upon amount which is collected periodically (incl safe custody)	User Fees	
	Water Users Know Roles	Each water user is being accountable	Users	
	<u>Identified, but not included in matrix:</u> A strong PPP Approach, Community Attitude, Hygiene and Sanitation, Land Tenure System, Location of Water Services, Presence of Political Parties, Safe Custody of Water Fees, Transparency and accountability, Tree planning, Vandalism			
	Environmental & Water Resources	Quantity of water available, including availability of water (groundwater, reservoirs, rivers, and rainwater). Includes conducting hydrogeological assessments for groundwater. Seasonal variation (wet season and dry season fluctuations), but also larger climatic changes such as drought and desertification, and geography	Water Resource Management	
<u>Identified, but not included in matrix:</u> Absence of Data, Culture				

Context	Original Name	Definition	Common Factor Category
Mille	Coordination	Communication and collaboration between Woreda sector offices, with Woreda office and the community, Woreda office and NGOs.	Coordination
	Finance	Budget available for use which is allocated from all sources including the government, NGOs and tariffs.	Financing
	Spare Part Supply	Availability of spare parts, equipment, and machinery.	Hardware
	Woreda Capacity	Capacity and awareness of Woreda administration offices	Local Capacity
	Skilled Water Technicians	The ability of technicians to repair and maintain minor and major problems.	Mechanics
	Water Demand	Increase in population increases water demand. In addition, the amount of water resource and infrastructure affects the number of people that can be served by the water schemes	Planning
	Proper Use	Community's sense of ownership, proper use and management of schemes. Awareness and participation of the community and responsibility and capacity of the community.	Users
	Water Quality	The quality of water during extraction and during distribution and use. This includes proper hygiene.	Water Quality
	Water Resources & Infrastructure	Available water resources, planning and construction of schemes, management of existing schemes and study of potential of water sources.	Water Resource Management
South Ari	Community	Participation by the community in aspects of service construction and provision.	Community
	Coordination	Coordination of woreda offices, zone offices, kebele administrators, and the community, with a common plan. Coordination on planning activities, monitoring water schemes, training, sharing resources (technical, material, and financial resources), and sharing information.	Coordination
	Finance	Finances available through budget allocated by the government, contributed by the community, or funded through external sources	Financing
	Capacity Building	Skills and training for existing human resources or the community, trainings and capacity building can be related to technical skills such as for O&M of the schemes (when "experts" do not have enough skills), but also can relate to hygiene, sanitation, or management in general. Experts, professionals, "skilled manpower". These experts are needed in both long-term presence but also short term "technical support" required for site selection or construction	Local Capacity
	Monitoring & Information	Monitoring and evaluation of scheme functionality and use, employing monitoring technologies. Also includes gathering asset inventory information about location of schemes and monitoring of the WASHCos themselves. Information related to scheme placement and functionality but also sharing ideas, results, and lessons. Knowledge about ongoing activities.	Monitoring
	O&M	Operations required for upkeep and continual functioning of the infrastructure, including technical O&M (including breakdown of infrastructure) but also including management.	O&M
	Planning & Construction	Planning and constructing/development/implementation of infrastructure to increase coverage (reach places that have not been reached) or to replace broken down infrastructure.	Planning
	Policy	Existing governmental regulation or policy, including currently practiced governmental procedures such as mandates, responsibilities and commitments, and reporting.	Regulations
	Proper Use of Water Schemes	Scheme misuse and lack of protection by community as a challenge.	Users
	Environmental & Water Resources	Quantity of water available, including availability of water (groundwater, reservoirs, rivers, and rainwater). Includes conducting hydrogeological assessments for groundwater. Seasonal variation (wet season and dry season fluctuations), but also larger climatic changes such as drought and desertification, and geography	Water Resource Management
<u>Identified, but not included in matrix:</u> Absence of Data, Culture			

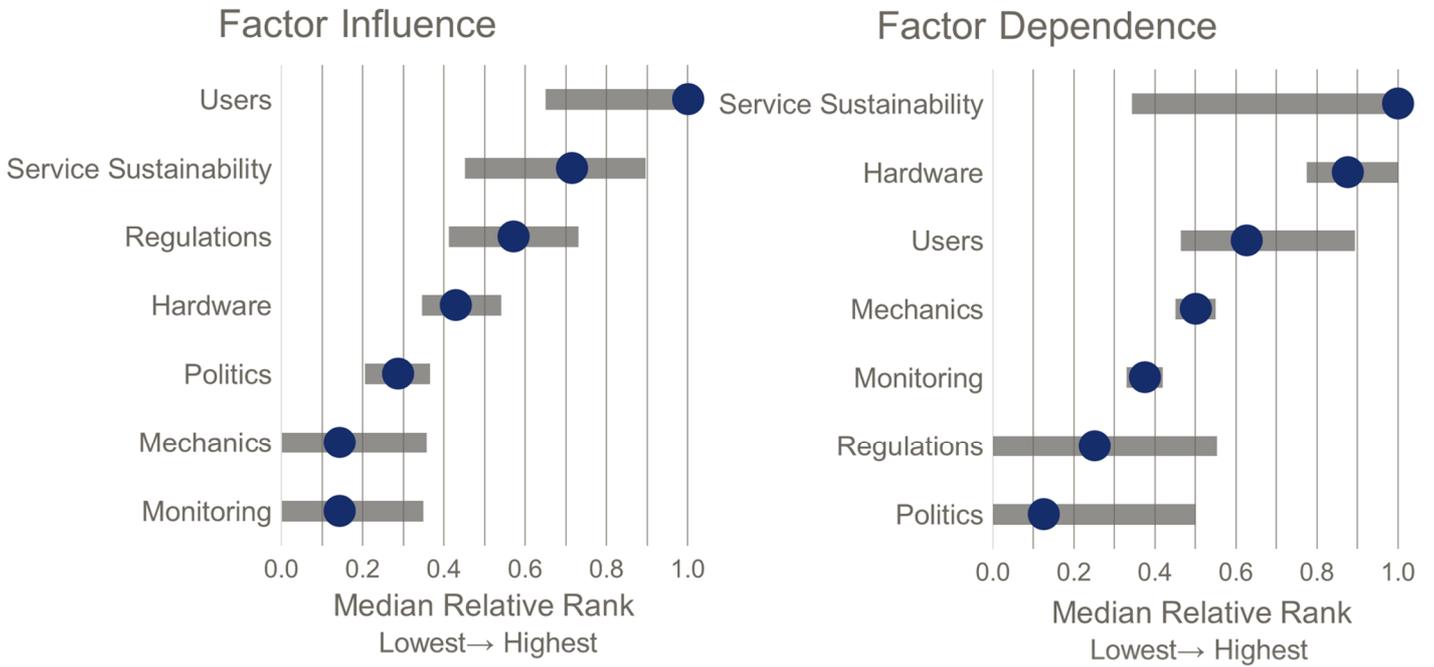


Figure S1. Normalized rank scores for Influence and Dependence from Kamuli overlaid onto full ranges of rank scores for all contexts where the factor was present. These factors represent 8 of the 14 total common factors identified across all contexts.

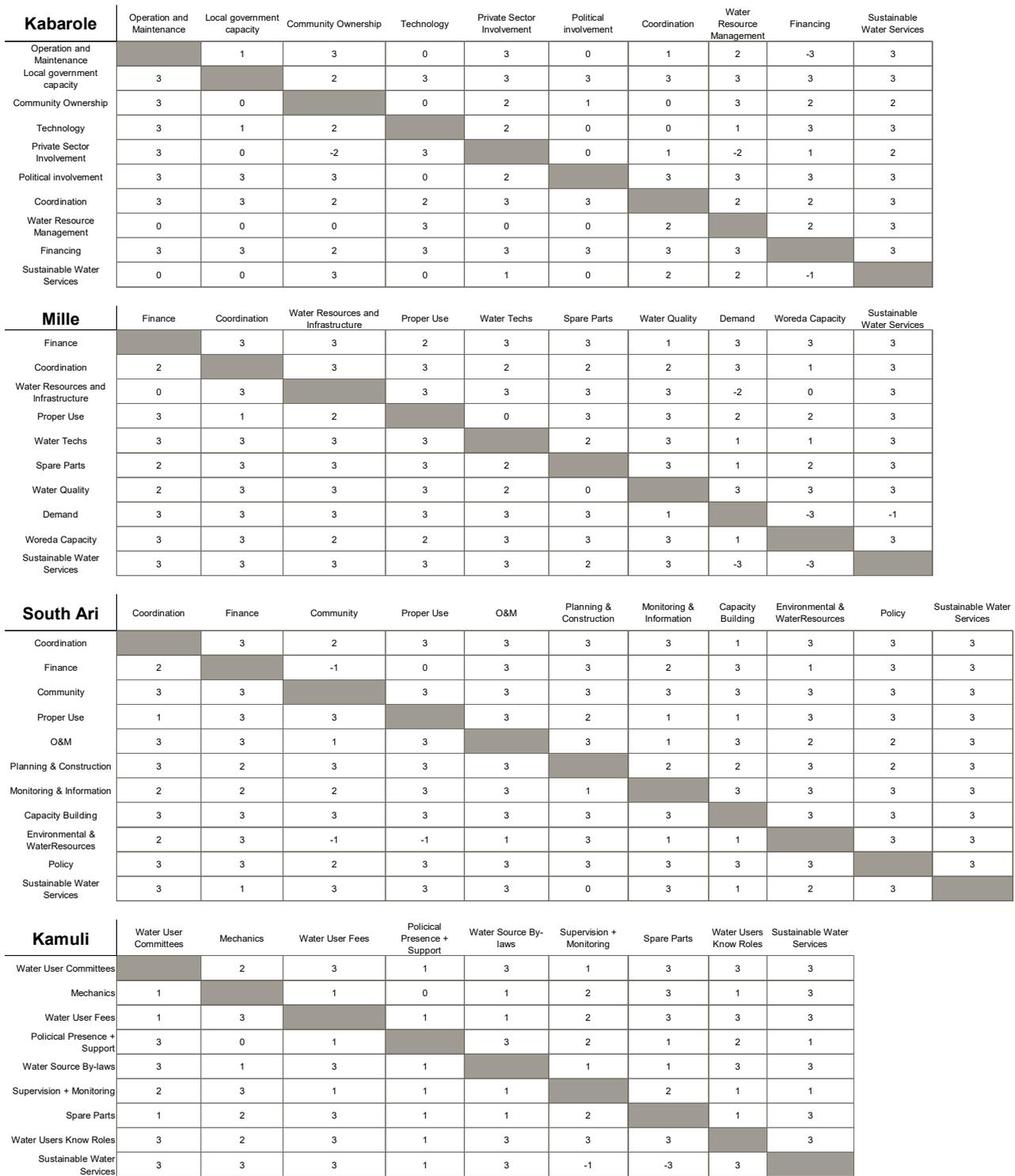


Figure S2. Cross Impact Matrices by context representing the interaction of factors where each cell contains the strength and polarity of influence from the factor in the row onto the factor in the respective column. Strength is represented as 0 – no connection, 1 – weak influence, 2 – moderate influence, 3-strong influence and polarity is represented as positive (+/no sign) or inverse (-).

Table S4. Feedback loops common to two or more contexts with low, average and high rank where present. (X) indicates feedback loop was present in that context, (*) indicates one or more factors in the loop was not present in that context's cross-impact matrix

Rank			Feedback Loop	Length	Contexts	South Ari	Kamuli	Kabarole	Mille
Avg	High	Low							
2	1	2	Users → Sustainability	1	2 / 3		X	*	X
12	7	16	Financing → WRM → Coordination → Sustainability	3	2 / 3		*	X	X
14	8	19	Financing → WRM → Sustainability	2	2 / 3		*	X	X
55	35	74	Users → Regulations → Sustainability	2	2 / 2	X	X	*	*
100	57	142	Coordination → Local Capacity → Financing → Sustainability	3	2 / 3		*	X	X
158	127	188	Local Capacity → Sustainability	1	2 / 3	X	*		X
204	109	299	Financing → WRM → Hardware → Sustainability	3	2 / 3		*	X	X
230	194	265	Coordination → Sustainability	1	2 / 3	X	*	X	
233	139	327	Financing → WRM → Coordination → Hardware → Sustainability	4	2 / 2	*	*	X	X
311	23	599	Financing → WRM → Coordination → Local Capacity → Sustainability	4	2 / 3		*	X	X
333	3	662	Financing → Local Capacity → Sustainability	2	2 / 3		*	X	X
337	38	635	Coordination → Local Capacity → Sustainability	2	2 / 3		*	X	X
337	99	574	Coordination → WRM → Hardware → Financing → Sustainability	4	2 / 2	*	*	X	X
355	12	698	Financing → Local Capacity → Coordination → Sustainability	3	2 / 3		*	X	X
372	355	389	Coordination → O&M → Local Capacity → Sustainability	3	2 / 2	X	*	X	*
584	450	717	Coordination → Local Capacity → Financing → WRM → Sustainability	4	2 / 3		*	X	X
701	572	829	Users → Hardware → Mechanics → Sustainability	3	2 / 3	*	X		X
Loop frequency where factors present						4/14 (26%)	3/3 (100%)	13/15 (86%)	14/15 (93%)

Table S5. Influence, dependence and feedback rankings for common factors, by leverage point criteria

Factor	Influence Rank				Dependence Rank				Feedback Rank			
	Kabarole	Kamuli	Mille	South Ari	Kabarole	Kamuli	Mille	South Ari	Kabarole	Kamuli	Mille	South Ari
Community	4			1	6			7	5			5
Coordination	5		5	3	2		1	4	2		2	3
Financing	3		2	8	1		3	2	1		4	8
Functionality	1	3	1	5	8	1	1	1				
Hardware	6	5	4		4	2	3		8	2	6	
Local Capacity	7		3	1	1		5	5	4		8	4
Mechanics		7	4			5	3			3	5	
Monitoring		7		5		6		6		5		9
O&M			6	3				2	3			2
Planning			3	4			4	3			7	6
Politics	8	6			2	8			7			
Regulations		4		2		7		2		4		1
Users		1	7	7		4	1	4		1	3	7
WRM	2		6	9	7		1	3	6		1	10

Table S6. Influence, dependence and feedback rankings for common factors by context

Factor	Kabarole			Kamuli			Mille			South Ari		
	Influence	Dependence	Feedback									
Community	4	6	5							1	7	5
Coordination	5	2	2				5	1	2	3	4	3
Financing	3	1	1				2	3	4	8	2	8
Functionality	1	8		3	1		1	1		5	1	
Hardware	6	4	8	5	2	2	4	3	6			
Local Capacity	7	1	4				3	5	8	1	5	4
Mechanics				7	5	3	4	3	5			
Monitoring				7	6	5				5	6	9
O&M		3	3							6	2	2
Planning							3	4	7	4	3	6
Politics	8	2	7	6	8							
Regulations				4	7	4				2	2	1
Users				1	4	1	7	1	3	7	4	7
WRM	2	7	6				6	1	1	9	3	10

Formatting reversed for dependence, a high score is more desirable than a low score (more versus less independent). Note that multiple factors can have the same rating within a context based on values in rows and columns of cross-impact matrix.