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The Productive Use of Rural Piped Water in Senegal

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ABSTRACT: Over the past decade there has been a growing interest in the potential benefits related to the productive use of rural piped water around the homestead. However, there is limited empirical research on the extent to which, and conditions under which, this activity occurs. Using data obtained from a comprehensive study of 47 rural piped water systems in Senegal, this paper reveals the extent of piped-water-based productive activity occurring and identifies important system-level variables associated with this activity. Three-quarters (74%) of the households surveyed depend on water for their livelihoods with around one-half (54%) relying on piped water. High levels of piped-water-based productive activity were found to be associated with shorter distances from a community to a city or paved road (i.e. markets), more capable water system operators and water committees, and communities that contributed to the construction of the piped water system. Further, access to electricity was associated with higher productive incomes from water-based productive activities, highlighting the role that non-water-related inputs have on the extent of productive activities undertaken. Finally, an analysis of the technical performance of piped water systems found no statistically significant association between high vs. low levels of productive activity and system performance; however, a positive relationship was found between system performance and the percentage of households engaged in productive activities.

KEYWORDS: Multiple-use water services, domestic plus, technical performance, water committee capacity, rural piped water, Senegal

INTRODUCTION

The approach to the provision of rural/peri-urban water services has evolved considerably over the past several decades. During the 1980s, the predominant focus was on providing water for domestic uses – i.e. for drinking, cooking, washing, and bathing. This emphasis was in part due to the UN's International Drinking Water Supply and Sanitation Decade (1981-1990), when 'water and sanitation for all' became an international priority. While progress was made during this decade, many of the installed water systems fell into disuse within a few years of their installation (Buckley, 1999). Inadequate funds for system operation, maintenance, and repair; poor management systems; and the use of inappropriate technology were some of the main reasons for system failures (Therkildsen, 1988; Cairncross, 1992).

In response to these challenges, a demand responsive approach to the provision of water services emerged in the 1990s, following the 1992 Dublin Statement on Water and Sustainable Development.

Some attention has also been given to post-construction support as a way to sustain services (Whittington et al., 2009). The four principles of the Dublin Statement – (1) to manage water resources to protect natural ecosystems; (2) to adopt a participatory approach to water system development and management; (3) to ensure women play a central role in the safeguarding and management of water; and (4) to recognise water as an economic good within the context of the human right to water – create a 'holistic approach' that continues to guide water services development today. The lessons learned from the 1980s combined with a greater emphasis on user demands and willingness/ability to pay for water were found to have a positive impact on the sustainability of water services (Sara and Katz, 1998; DFID, 2006). However, water projects continued to focus on supplying water predominantly for a single use – i.e. for domestic use or irrigation.

Today, the development of domestic water services is led by the WASH (water, sanitation, and hygiene) paradigm that emphasises the provision of safe and clean water for drinking, sanitation, hygiene, and other domestic activities. The priority given to drinking water has its origin in human rights law and key texts such as the Millennium Declaration and the subsequent Millennium Development Goals (MDGs) (Hall et al., 2013). This emphasis on drinking water has resulted in targeting international resources at this narrower development objective.

In the early 1970s, an important study on domestic water use in East Africa developed three categories of water use: 'consumptive' (drinking and cooking), 'hygiene' (washing, cleaning and bathing), and 'amenities' (watering lawns and other non-essential activities) (White et al., 1972). In a follow-up study some 30 years later, 'productive uses' was added as a fourth category (Thompson et al., 2001). Productive uses were considered to include "consumption by livestock (e.g. cattle, goats, pigs and sheep), brewing beer, distilling gin, making fruit juice, brick-making and the construction of homes, and irrigating tree and horticultural crops" (Thompson et al., 2001: 31).

Thompson et al. (2001) argued that the productive use of water around the homestead was a largely unrecognised, but important factor supporting livelihoods. Their research helped formulate a new approach to water service provision called multiple-use water services (MUS) that was initially championed by the IRC (International Water and Sanitation Centre) through the PRODWAT (productive uses of water at the household level) thematic group.

MUS is a 'whole water' approach that responds to the many water needs of rural and peri-urban households by creatively designing water services around domestic and livelihood activities (de Vries et al., 2004; Penning de Vries, 2006; van Koppen et al., 2006; Renwick et al., 2007; World Bank et al., 2009; Smits et al., 2010; Restrepo Tarquino, 2010; Srinivasan et al., 2012). The approach has also been applied to the irrigation sector where water from irrigation canals and reservoirs is used for domestic and productive uses around the homestead (Bakker et al., 1999; Meinzen-Dick and van der Hoek, 2001; Renwick, 2001; Smith, 2004; Li et al., 2005).

While there is currently no official definition of MUS, there are a number of definitions that help bound the scope of the approach. For example, van Koppen et al. (2006: v) define MUS as "a participatory, integrated and poverty-reduction focused approach in poor rural and peri-urban areas, which takes people's multiple water needs as a starting point for providing integrated services, moving beyond the conventional sectoral barriers of the domestic and productive [i.e. irrigation] sectors". More recently, Martin Dery (founder of the NGO ProNet North in Ghana) described MUS as entailing "a systemic approach to water provision that recognizes the alternative and competing uses of water in a changing environment. The approach is comprehensive, participatory, and informed by indigenous knowledge and practice systems and aims to increase the efficiency, reliability, and livelihood resilience under climate change. Dignity, inclusion, sustainability, and multi-stakeholder involvement are essential to the MUS approach" (from Srinivasan et al., 2012: 14). Thus, the MUS approach seeks to overcome the balkanisation of planning for domestic water supply and irrigation systems and places community participation and ecosystem/watershed concerns at the centre of development efforts.

The MUS 'whole water' approach is largely consistent with the 'holistic approach' to water services development embodied in the Dublin Statement. Thus, the MUS design and implementation guidance – see, in particular, Adank et al. (2012), Winrock International (2012), and Maksimović et al. (2014) – could provide a way to operationalise the Dublin Statement. The potential for the MUS approach to integrate the domestic and productive/irrigation activities of the water sector in the context of the environment, health, and livelihoods makes it an important challenger to the WASH paradigm.[1]

During the mid-2000s, the Water and Sanitation Program (WSP), World Bank, initiated a multi-country research project (in Colombia, Senegal, and Kenya) to study the productive use of domestic water, poverty reduction, and water system sustainability. While there was a growing body of case study-based research on MUS that focused on quantifying the observed or potential earnings associated with the productive use of water in particular settings, there was limited empirical data available. Two important questions from a policy and planning perspective, however, remained largely unexamined: (1) What household- and community-level characteristics are associated with increased productive use of domestic water supplies? and (2) Is there any evidence that higher rates of productive use of domestic water systems are associated with improved system performance? These are the knowledge gaps that the current study seeks to address.

This paper is structured as follows. Section 2 provides a description of the research design and sample frame, presents the methodology used to classify whether a community has a high vs. low level of piped-water-based productive activity, and describes three indexes used to assess the technical performance of the piped water systems. Section 3 presents the results from the analyses. It explores the extent of household participation in water-based productive activities, identifies the system-level characteristics associated with high levels of productive activities, and discusses the association between piped-water-based productive activity variables and the technical performance indexes. Section 4 discusses the implications of the findings and Section 5 concludes the paper.

METHODOLOGY

Research design and sample frame

To limit the scope of the WSP-funded research, the study focused on the productive use of water obtained from rural reticulated (i.e. piped) water systems. Given the various types of reticulated systems that exist – such as surface water gravity fed, surface water pumped, or groundwater pumped systems – further assumptions were made within each country to ensure that the data collected were comparable across the three countries.

In Senegal, rural access to improved water has been steadily improving over the past decade. In 2011, the percentage of the rural population that used an improved water source was 59, compared to 50 in 2000 (WHO and UNICEF, 2013). Of the households with access to an improved source, 18% had access to water piped into their house or yard and 41% had access to 'other improved' water sources, including public tap/standpipes, tubewell/boreholes, protected dug wells, protected springs, or rainwater collection.[2]

[1] While several approaches have been created to integrate the development and management of water services – such as Integrated Water Resources Management (IWRM), Participatory Watershed Management (PWM), Payments for Ecosystem Services (PES), and Water, Sanitation, and Hygiene (WASH) – MUS is the most recent approach. See Srinivasan et al. (2012) for a discussion of how the concept of MUS has emerged to challenge the current dominant WASH paradigm.

[2] The rural population without access to an improved water supply uses water from unprotected dug wells, unprotected springs, carts with tanks/drums, tanker trucks, surface water, or bottled water.

The research focus on rural reticulated systems meant that the study in Senegal targeted rural electric-powered pumped borehole systems (with limited distribution systems), hereafter referred to as *piped water systems*, which could be found in eight of the country's 14 regions. Over the past decade, Senegal has almost doubled the number of these systems to 1,400 (in 2009) from 747 (in 2000) (IRC, 2009). The systems were primarily designed to provide water for domestic use, but a significant number also provide water for livestock and, to a lesser extent, agriculture. Given that the primary focus of these systems is to provide water for domestic use, the systems can be classified as 'domestic plus'.

Senegal can be divided into three distinct zones – the Northern, Central, and Southern zones. Each zone has specific hydrological, geographic, and climate characteristics that were considered when selecting regions for the study. The three zones are subdivided into 14 regions. From the eight regions located in the Northern and Central zones, four were selected (St. Louis, Matam, Diourbel, and Kaffrine) based on an assessment of the agricultural and livestock activity occurring within a region, and the desire to have some variation of hydrological, geographic, and climate characteristics.

Within these four regions, a database was developed of all the rural piped water systems that had a functioning water committee – known as an ASUFOR (*Associations d'usagers de forage;* Associations of borehole users). In Senegal, large-scale reforms have specifically targeted the sustainability of rural water services and have led to the creation of an ASUFOR in two-thirds of the rural water supply systems (WSP, 2010).

For this study, 47 rural piped water supply systems were selected from the database of ASUFOR systems using stratified random sampling – 14 in Diourbel, 12 in Kaffrine, 10 in Matam, and 11 in St. Louis. The sample population was stratified using ex ante estimates of the extent of agricultural and livestock activity supported by each piped water system. The rationale for this stratification was to develop a data set where similar piped water systems that supported varying levels of productive activity could be compared.

Within the 47 systems, a total of 1860 household surveys were completed, as well as 47 community leader interviews, 46 water committee interviews, 44 water operator interviews, 15 focus groups with women, and 47 engineering assessments of existing infrastructure. The household survey included modules on household composition, access to and use of water, access to sanitation, income and expenditures, and health. In each community, the households were randomly selected for the study. The fieldwork was undertaken from May to September, 2009.

Classifying piped-water-based productive activity

The following three system-level variables were developed from household survey data to measure the extent of piped-water-based productive activity occurring in each system:[3]

- *Household Productive Income* (piped water) ($/month): Mean household monthly income (US$) from productive activities that use water from the piped system (90% trimmed means).[4]
- *Extent of Productive Activity* (piped water) (%): Percentage of households that undertake (one or more) productive activities that are supported by water from the piped system.

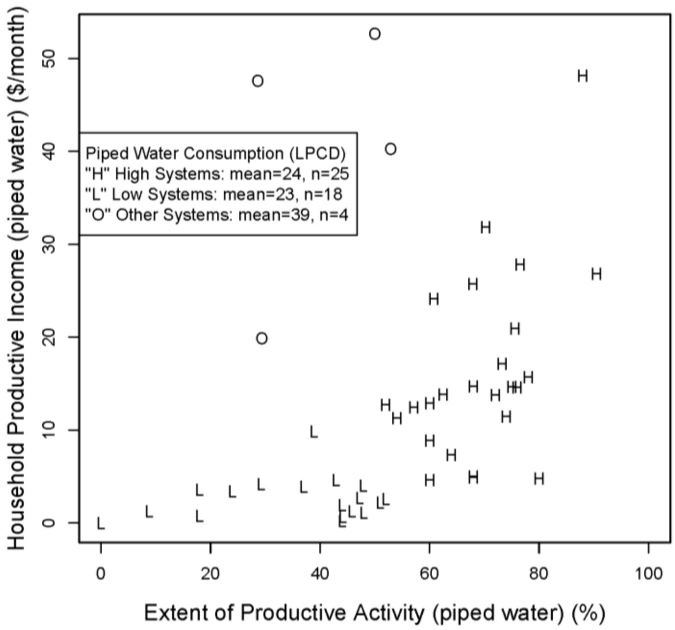
[3] In addition to piped water use, data were also collected on the consumption and use of non-piped water by households.

[4] A review of the data revealed that using 90% trimmed means to calculate the productive use income variable limited the potential impact of outliers. While obvious data entry errors were corrected post-survey, a small percentage of outliers that could not be adjusted using objective criteria remained in the data. It is likely that the remaining outliers were the result of data entry errors on the PDAs (personal digital assistants), rather than households having extremely high incomes (or water volumes in the case of the third extent of productive activity variable).

- *Piped Water Consumption* (LPCD): Mean volume of water (LPCD – litres per capita per day) used by households from the piped system (90% trimmed means).

While each of these variables provides unique information on specific components of piped-water-based productive activity, taken together they offer a more comprehensive way to evaluate the extent of productive activity being undertaken. By using a k-means clustering algorithm (Hartigan and Wong, 1979), three distinct groups of systems were identified and labelled as 'High', 'Low', and 'Other' (see Figure 1). Table 1 presents the descriptive statistics relating to the classification of High/Low/Other systems. T-tests between the systems in the High and Low groups confirmed that the differences between them for the first two variables in Table 1 were statistically significant ($p<0.0001$). However, household piped water consumption was similar in the High and Low groups (24 and 23 LPCD, respectively). These two groups also had comparable levels of household access to piped water (i.e. to public taps – High 57%, Low 55%; private taps – High 34%, Low 27%; and/or neighbour's taps – High 5%, Low 6%). Thus, the High and Low groups differ in the amount of productive income earned and the percentage of households in the community undertaking productive activities, but not in the volume of piped water consumed.

Figure 1. Graphical results from the K-means clustering (H=High system, L=Low system, O=Other system).



The four systems that fell into the Other group reported a high level of productive income from piped-water-based activities and very high household piped water consumption (mean=39 LPCD), but had a lower percentage of households in each system engaged in productive activities. Thus, the Other systems can be described as having fewer households engaged in productive activities, but those that did, generated significantly more income from these activities and consumed more water when compared to households in the High group of systems. Given the emphasis of this paper on exploring the system-level variables that differentiate High vs. Low levels of productive activity, the subsequent analysis focuses on these two groups of systems.

Table 1. Descriptive statistics for the High, Low, and Other group of systems.

Variable Name	High group			Low group			Other group			T-test (High vs. Low)
	N	Mean	St. Dev.	N	Mean	St. Dev.	N	Mean	St. Dev.	p-value
Household Productive Income (piped water) (US$/month)	25	$16	$10	18	$3	$2	4	$40	$14	<0.0001
Extent of Productive Activity (piped water) (%)	25	69%	10%	18	36%	16%	4	40%	13%	<0.0001
Piped Water Consumption (LPCD)	25	24	3	18	23	7	4	39	8	0.4958

Classifying the technical performance of rural water supply systems

The following three technical performance indexes were created using data from the household survey and interviews with the water committees:

- *Percent of System Operational*: The percentage of major system components (e.g. household connections, shared private taps, public stand pipes, cattle troughs, agricultural water tanks, and tanker fill stations) that were operational at the time of the survey (developed using data from the water committee interview).
- *System Breakdowns*: A measure of the number of system breakdowns that have occurred in the past year (as reported by respondents in the household survey).
- *Duration of Breakdown*: A measure of the time (in days) it took to repair the last system breakdown (as reported by respondents in the household survey).

For each of the three indexes, the values were normalised to fit a 0 to 1 scale, where '0' signifies a poor level of piped water system performance and '1' signifies a high level. For additional information on the indexes, see the Appendix to this paper.

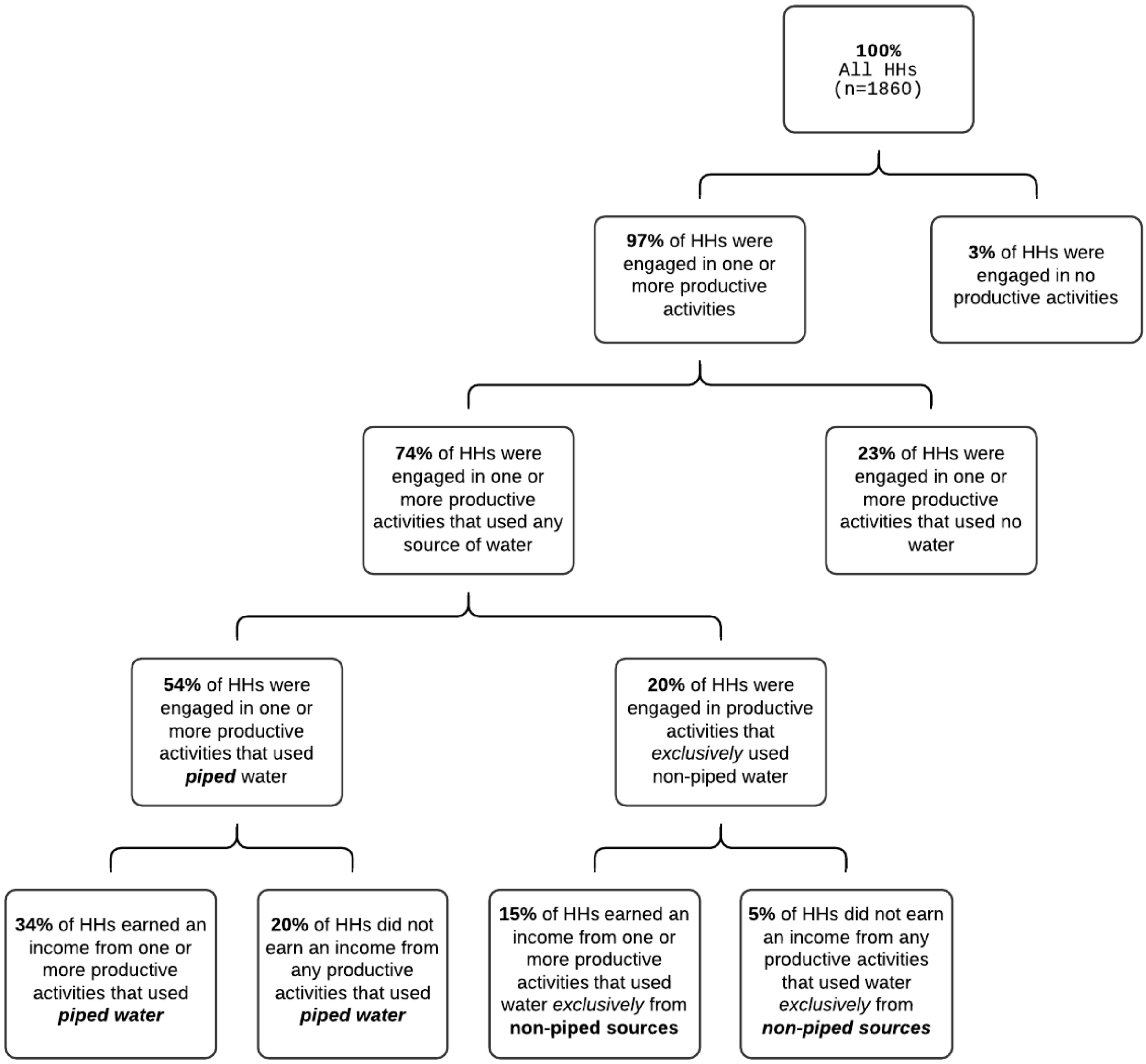
RESULTS

Extent of household participation in water-based productive activities

Of the households surveyed, 29% had access to a privately owned tap, 55% to public taps, and 36% to unprotected public wells that were not part of the piped water systems. Households also reported collecting rainwater (15%) and obtaining water from handpumps (8%), surface sources (7%), a neighbour's private tap (5%), a neighbour's private well (1%), and vendors (1%). Thus, 89% of the households surveyed reported using water from the piped water system (i.e. from private taps, public taps, or a neighbour's private tap). The mean number of water sources used by households during the dry and wet seasons was 1.4 and 1.3 (st. dev. of 0.5 for both), respectively.

The majority of piped water systems were designed to support productive activities. For example, 43 of the 47 systems had at least one cattle trough (the average number per system was 1.9). Of the remaining four systems, two had at least one water tank intended to provide water for small-scale agriculture (known locally as a *bac jardin*). Some 27 (57%) of the systems studied had at least one of these water tanks.

Figure 2. Extent of water-based productive activity.



Nearly every household (97%) surveyed participated in one of the productive activities included in the household survey (i.e. gardening, agriculture, livestock, commerce, services, and/or manufacturing activities) – see Figure 2. Almost three quarters (74%) of households reported using water (from any source) to support their activities, and one-half (49%) of households generated an income from these productive activities. This productive income represented one-half of the total household income for these households. When considering all households, income from water-based activities accounted for a quarter (25%) of total household income. Over one-half (54%) of the surveyed households were engaged in activities that relied on the piped water system.[5] Interestingly, one-fifth (20%) of the

[5] The same general patterns in the percentage of households engaged in water-based productive activities were found in Colombia and Kenya – see Hall et al. (2013).

households exclusively used non-piped water to support their productive activities and three-quarters of these households earned an income from this activity.[6] These data show the important role that traditional water sources, such as public wells, continue to have in the communities surveyed.

Most of the households surveyed were engaged in agriculture[7] (in field plots) and/or the raising of livestock (Table 2). Whereas 84% of households were involved in agriculture, crops are predominantly rain-fed, and only 1% of this group used the piped water system to irrigate their crops.

Table 2. Extent of household (HH) participation in water-based productive activities (n=1860).

Productive activities	% of HHs participating in this activity	% of HHs using *any* water source for this activity	% of HHs using the piped water system for this activity
All systems (n=1860)			
1. Gardening	8	6	4
2. Agriculture	84	4	1
3. Livestock	69	69	50
4. Commerce	33	5	4
5. Services	21	3	2
One or more productive activities	97	74	54
High systems (n=1001)			
1. Gardening	9	7	5
2. Agriculture	90	5	1
3. Livestock	74	74	66
4. Commerce	33	6	5
5. Services	21	4	4
One or more productive activities	97	78	69
Low Systems (n=692)			
1. Gardening	8	6	4
2. Agriculture	81	5	0
3. Livestock	57	57	32
4. Commerce	33	3	2
5. Services	22	2	1
One or more productive activities	96	63	36

[6] The one-fifth (20%) of households engaged in productive activities that exclusively used non-piped water had higher median annual household incomes (US$1,833 versus US$1,340) and significantly more livestock units (9.0 LSU versus 2.8 LSU) than the 54% of households engaged in productive activities that did use the piped water system. The group of households that exclusively used non-piped water and earned an income from productive activities (15% of sample) had the highest median annual income (US$2,178). Conversely, the small group of households that exclusively used non-piped water and did not earn an income from productive activities (5% of sample) is one of the poorest groups with a median annual income of US$853. Therefore, non-piped sources were critical for higher incomes for all but the poorest groups, who were unable to earn income from their water-based activities.

[7] Typical agricultural crops include millet (grown by 84% of households engaged in agriculture), beans (65%), peanuts (59%), sorghum (37%), and maize (25%). Almost half of all households engaged in agriculture reported selling at least some agricultural crops. The top three cash crops were peanuts, beans, and sesame. Maize and sorghum are most likely consumed by the household. Around 8% of the households surveyed maintained kitchen gardens around the homestead. The top five garden crops were eggplant, onions, tomatoes, cabbage, and peppers.

Raising livestock was found to be the most important productive activity that relied on the piped water system, both in terms of the percentage of households engaged and the amount of income generated. Over two-thirds (69%) of the households surveyed raised livestock and used a water source to support this activity. Of these households, three-quarters (73%) used water from the piped water system to support their animals. Further, one-half (49%) of the households surveyed owned at least four cattle or an equivalent number of livestock units (LSU).[8] Forty-three of the 47 systems surveyed accommodated livestock watering through the installation of at least one cattle trough.

Households classified as having High levels of productive activity showed slightly higher levels of agriculture and gardening, but the differences were more significant when looking at livestock-raising. In the High group, 74% of households participated in livestock-raising, compared to 57% in the Low group. Although commerce and service activities engage a small number of households in comparison to agriculture and livestock, the percentage of people using water for these activities was twice as high in the High group. The High group is not only more likely to use any water source for these activities, but is more than twice as likely to use a piped water source as the Low group.

System-level characteristics associated with high vs. low levels of productive activity

High and Low groups of systems were compared with respect to selected system-level variables. Altogether 24 variables were included in the analysis that covered a wide range of community- and system-level characteristics. For example, variables were developed to describe the size of the community and length of its piped water network, and the location of the community relative to the nearest paved road and city. Other variables captured data on the capacity and general satisfaction of the water committee and water system operators. Variables were also developed to describe the extent of community engagement in the development of the piped water system. Each of the 24 variables is described in the Appendix to this paper.

The analysis revealed that six system-level variables were significantly associated with high levels of piped-water-based productive activity (Tables 3 and 4):

- *Distance to Road* (km): High systems were located at a shorter distance from roads than Low systems.
- *Distance to City* (km): High systems were located at a shorter distance from cities than Low systems.
- *Water Committee Activities*: High systems had, on average, water committees that performed a greater number of activities than water committees in the Low group.
- *Operator Experience*: Water system operators in High systems had more experience, typically, than water system operators in Low systems.
- *Percentage of Households that Contributed to the System*: High systems had, on average, higher percentages of households that made up-front cash contributions to the construction of the system than Low systems.
- *Community Initiated*: The construction of High systems was more often initiated by the community than Low systems.

[8] Livestock Unit (LSU) conversion factors in Senegal: horses (0.8), cattle (0.5), donkeys (0.4), pigs (0.2), sheep (0.15), goats (0.1), rabbits (0.02), and chickens (0.01).

Table 3. Comparison of system-level variables for High vs. Low productive activity groups.

Variable	High				Low				T-test High vs. Low
	N	Median	Mean	St. Dev.	N	Median	Mean	St. Dev.	p-value
Population served	25	4424	5118	3737	18	3557	5182	5278	0.965
Distance to road (km)	25	5	8	10	18	18	20	13	**0.005**
Distance to city (km)	25	14	16	9	18	35	36	22	**0.001**
System length (km)	25	9.57	15.2	14.78	18	5.69	13.87	18.6	0.788
System age (years)	25	17	15	8	17	20	18	8	0.250
Water committee activities	25	12.0	11.1	2.3	17	8.0	8.5	2.7	**0.002**
Percentage of households attending WC meetings	25	36%	38%	11%	18	37%	37%	14%	0.683
Operator activities	24	4.0	3.7	1.7	16	3.5	3.6	1.0	0.807
Operator satisfaction	24	5.0	4.2	1.1	16	5.0	4.5	1.0	0.342
Percentage of households that contributed to system	25	35%	37%	28%	18	12%	15%	13%	**0.002**
User ownership (perception)	25	86%	84%	12%	18	85%	84%	7%	0.971
Percentage of households dissatisfied w/ water services	25	51%	52%	25%	18	59%	58%	28%	0.449
Percentage of households w/ national grid electricity	25	0%	20%	25%	18	0%	9%	16%	0.110
LSU	25	3.3	4.1	3.4	18	1.6	7.4	10.5	0.213
Index: Percent of system operational	25	1.0	0.96	0.10	17	0.99	0.83	0.33	0.125
Index: System breakdowns	25	0.79	0.77	0.15	18	0.78	0.71	0.33	0.320
Index: Duration of breakdowns	25	0.56	0.52	0.28	18	0.44	0.44	0.30	0.392

System-level characteristics associated with the productive activity variables

To refine the above analysis, the High/Low distinction was replaced by the three composite variables used to create the two groups. This analysis sought to identify the variables that were statistically significant predictors of the three productive activity variables. The analysis used a forward-backward step-wise ordinary least squares regression procedure using the Bayesian Information Criterion (BIC) to evaluate the statistical significance of the independent variables (Schwarz, 1978).[9] Of the 18 independent variables included in the analysis, seven were found to be significant, with p<0.05, in one

[9] BIC is a widely used criterion for model selection when the number of possible explanatory variables is large. BIC evaluates how well the independent variables explain the dependent variable, but subtracts a penalty for the number of variables in the model. This penalty causes BIC to favour models with fewer independent variables, thus avoiding over-fitting the model with variables having spurious associations with the dependent variable. The smaller models developed using BIC are likely to be easier to interpret and more likely to be true than models selected using AIC (the Akiake Information Criterion, another widely used evaluation of model fit) (Schwarz, 1978). We used the stepAIC function in R (Venables and Ripley, 2002; R Core Team, 2012) to select independent variables that significantly improved the measure of model fit. Most, but not all, of these selected variables had p<0.05.

or more of the three models (Table 5).[10] An interpretation of these models is provided in Section 4; however, it is noteworthy that the number of activities undertaken by the water committee was found to be significant in all three models.

Table 4. Comparison of system-level categorical variables for High vs. Low productive activity groups.

Variable	Description		High	Low	High vs. Low p-value[a]
Operator experience	Prior experience operating water system (None, Some, Very)	None	3	9	**0.002**
		Some	5	5	
		Very	16	2	
Community/Externally initiated	The development of the piped water system was initiated by a community/external entity	Community	22	9	**0.029**
		External	3	8	
Water conflicts	Reported water conflicts in village	Yes	1	2	0.556
		No	24	15	
Aware before construction	Was the village aware that the water system would be installed before the construction began	Yes	20	12	0.714
		No	5	5	
External technical support	The water committee received unpaid external help with repairs or maintenance	Yes	2	0	0.506
		No	23	17	
External non-technical support	The water committee received external help with billing, accounting, payments, or other administrative tasks	Yes	1	3	0.286
		No	24	14	
External financial support	The water committee received external financial support for operations and maintenance	Yes	4	3	1.000
		No	21	14	

[a] A Fisher's exact test (Agresti, 1992) was used to compare these seven categorical variables in the High vs. Low systems.

Piped-water-based productive activity and technical performance

While the High-Low analysis of system-level characteristics (Table 3) revealed no significant differences between High vs. Low levels of productive activity and the three technical performance indexes, a more refined analysis was undertaken to explore the association between the technical performance indexes (the dependent variables) and the three (independent) productive activity variables. The only significant relationship ($p<0.05$) found between technical performance and the productive activity variables occurred in the System Breakdowns model (Table 6). The model revealed a positive association between the index of system breakdowns and the percentage of households engaged in productive activities, and a negative association between the same index and increased water consumption. Since an index value of '1' signifies a high level of performance, these results imply that an increase in the percentage of households engaged in productive activities is associated with fewer system breakdowns

[10] Because only 44 of the 47 system operators were interviewed, separate models were run for the three operator variables (Operative Activities, Operator Satisfaction, and Operator Experience) to see if they were statistically significant predictors of the three extents of productive activity variables. The only operator variable that was found to be a significant predictor of the Extent of Productive Activity variable was the operator's experience. More experienced operators were associated with a higher percentage of households undertaking productive activities. The operator's experience explained 27% of the variation in the Extent of Productive Activity variable (R-squared=0.27, p=0.002, n=44).

and that an increase in water consumption is associated with more system breakdowns. In both of these cases the direction of causality is unknown. For example, it is not clear whether greater levels of productive activity lead to fewer system breakdowns or vice versa.

Table 5. Extent of productive activity models.

Independent variables	Household productive income (piped water) (US$/month)	Extent of productive activity (piped water) (%)	Piped water consumption (LPCD)
Intercept	-2.960***	43.232***	14.518***
Distance to road (km)	0.052***	-	0.197***
Distance to city (km)	-	-0.304*	-
Population served	0.00009*	-	-
System age (years)	-0.036.	-	-
Water committee activities	0.215**	2.570**	0.688.
Percentage of households that contributed to system	0.013.	-	-
Percentage of households with national grid electricity	1.771*	-	-
LSU	0.120***	-0.616*	-
External non-technical support (yes)	-	-25.208**	-
N	46	46	46
Multiple R-squared	0.675	0.520	0.250
Adjusted R-squared	0.615	0.473	0.215

Significance codes: *** p<0.001; ** p<0.01; * p<0.05; '.' p<0.1

Table 6. Models of technical performance against the extent of productive activity variables.

Independent variables	Index: Percent of System Operational	Index: System Breakdowns	Index: Duration of Breakdowns
Intercept	0.922***	0.811***	0.365.
Household productive income (piped water) (US$/month)	0.001	-0.001	0.000
Extent of productive activity (piped water) (%)	0.002.	0.003*	0.004.
Piped water consumption (lpcd)	-0.008	-0.010*	-0.005
N	46	47	47
Multiple R-squared	0.130	0.252	0.094
Adjusted R-squared	0.067	0.200	0.031

Significance codes: *** p<0.001; ** p<0.01; * p<0.05; '.' p<0.1

DISCUSSION

This paper provides evidence of the extent to which, and conditions under which, piped-water-based productive activity occurs in rural Senegal. The data show that three quarters (74%) of the households surveyed were engaged in water-based activities and that one-half (49%) of households earned an income from these activities. These findings are broadly consistent with Renwick et al.'s (2007) survey of the MUS literature, which found that between 60-70% of rural poor own livestock or have access to small cultivable plots, enabling them to benefit from MUS.

Livestock-raising is the most significant water-based productive activity in Senegal, but some gardening, agriculture, commerce, and service-related activities also rely on water. An analysis of water-based income found that it accounted for one-quarter (25%) of total household income (or one-half of total household income for those households engaged in income-generating water-based activities), which reinforces Thompson et al.'s (2001) argument that the productive use of water is a critical factor supporting livelihoods. Further, although one-quarter of households did not report earning an income from their water-based activities, these activities are critical to food security and nutrition, especially for women (Van Houweling et al., 2012). While the case study literature on MUS indicates that the extent and significance of productive activities are highly variable across countries (Smits et al., 2010; Moriarty et al., 2004), the findings from Senegal align with the general consensus that these activities provide important supplemental income or food for a large proportion of rural households.

Livestock ownership was found to be a significant predictor of piped-water-based income ($p<0.001$) (Table 5), highlighting the important role that animal husbandry plays in livelihoods in Senegal. However, the analysis also revealed that as the average number of livestock units increases, the percentage of households engaged in piped-water-based productive activities declines ($p<0.05$). This observation could indicate that there are limits to the extent of productive activity that can be supported in a community. These limits could relate to the availability of resources (such as water, land, and food for livestock), issues of social equity and access, and/or the market's ability to absorb additional water-based products/services without a collapse in price. Additional research is needed to answer these questions that fall beyond the scope of the study. However, they do indicate that efforts to scale-up productive activities must pay close attention to these potential constraints.

The analysis of the extent of water-based productive activity also revealed that one-fifth (20%) of households exclusively used non-piped water to support their productive activities (see Figure 2). The significance of non-piped water use raises an important question about how piped *and* non-piped sources can be better integrated into a multiple-use services (MUS) approach. Non-piped water sources may be preferred by households for some uses since they are generally free and can provide easy access (e.g. surface water used by livestock). Upgrading existing piped water systems to expand productive activities could ignore important benefits from productive activities supported by non-piped sources. Thus, *all* water sources used by a community should be included in any plans to provide water of sufficient quantity and quality to meet the diversity of demands expressed by households. Investment that seeks to enhance, protect, and maintain non-piped water sources as part of a broader vision of rural water services (which includes piped water) is likely to be a cost-effective strategy in areas near surface water that are highly reliant on livestock raising.

With regard to the conditions under which productive activity occurs, we found that productive use was negatively associated with distance to a paved road (Table 5), suggesting that access to markets catalyses productive use activities. Communities located far from a paved road and markets are confronted with comparatively greater transportation costs, which reduce the financial incentive for engaging in productive activities. A more refined analysis of the factors associated with each of the productive activity variables found that as the distance to markets increased, the number of households engaged in productive activities declined, but those who were engaged earn higher levels of income than those households undertaking productive activities nearer to markets. Hence, the intensity of productive activities, particularly the raising of livestock, undertaken by households varied with the distance of a community to a market. Put differently, the more remote communities tended to have fewer households engaged in the raising of livestock, but those households that did engage owned a greater number of livestock.

Further, the association between access to electricity and higher productive incomes (Table 5) highlights the role that non-water-related inputs can have on the extent of productive activities undertaken. This observation reinforces Van Houweling et al.'s (2012) observation that addressing the general (non-water-system-based) constraints to productive use via an integrated development model could enhance the amount of productive activities undertaken. These constraints include access to land, credit, and services such as electricity.

The positive association between high levels of productive activity and a greater number of activities undertaken by water committees (Table 3) and more experienced water system operators (Table 4) reinforces the notion that effective water committees and well-trained operators are important to the successful delivery of rural piped water services (Schouten and Moriarty, 2003). Focus groups conducted for this study showed that system reliability was another important factor for enabling productive activities (Van Houweling et al., 2012). While the technical performance of piped water systems was not found to be significantly different between High vs. Low groups of systems (Table 3), a greater percentage of households were found to engage in productive activities when there were fewer system breakdowns (Table 6). Further, those communities that received non-technical external support – indicating a possible lack of a capacity to manage the water system – were associated with lower levels of productive activity (Table 5). Thus, any effort to advance MUS in Senegal should pay careful attention to how the capacity of water committees/operators will be maintained/improved to ensure reliable water services are provided.

A more refined analysis of the system-level variables associated with each of the three productive activities variables found the number of activities undertaken by the water committee to be positively associated with each of the three productive activities variables (Table 5). This finding further reinforces the critical role of effective water system management in supporting productive activities.

The finding that community engagement in the development of the piped water supply system was positively associated with high levels of productive activity (Table 4) reinforces the potential value of a 'demand-driven' approach to water supply. Of the 32 systems whose development was reported to have been initiated by communities themselves (as opposed to an externally led intervention) (see Table A2 in the Appendix), 22 (73%) fell into the High group of systems (Table 4). In contrast, of the 14 systems that were reported to have been initiated by an external entity, only 3 (21%) fell into the High group of systems. Similarly, 37% of households surveyed in the High productive use systems reported contributing money, land, labour, material, and/or food for labourers to the construction of the water system, compared with 15% in the Low productive use systems (Table 3). Given the similarity in the design of the piped water systems studied, these data indicate that the demand-driven model for water services development is associated with greater levels of piped-water-based productive activity. Since data were not available on the historical development of the water systems (the average age of the systems was 17 years, st. dev. 9), it is not possible to comment on the specific types of water projects/programmes that are associated with high levels of productive activity. However, these findings suggest that a demand responsive and participatory approach to rural water service provision should remain a central part of the MUS toolkit.

The final analysis in this paper considered whether the technical performance of piped water systems was associated with greater levels of piped-water-based productive activity (Table 6). While no strong relationship was found between technical performance and productive activity, there is an indication that the two are related, although it is not clear whether technical performance enables greater productive activity or vice versa.

Finally, while the systems studied in Senegal were designed to support productive activities, they were primarily designed to provide water for domestic use.[11] If MUS-by-design systems begin to emerge in Senegal, it would be valuable to assess whether these systems support greater levels of productive activity and have greater technical and financial performance than the domestic plus systems studied in this research.

Conclusions

This paper provides important evidence of the extent to which and conditions under which the productive use of water occurs in rural Senegal. We found that water is critical to the livelihoods of rural households in Senegal and accounts for one-half of household income for those households engaged in income-generating productive activities. While the purposeful sampling of communities limits the generalisability of the findings, they do provide governments in countries with similar hydrological, geographic, and climate characteristics as Senegal with a starting point for identifying factors that might support greater levels of water-based productive activity. More research is needed to expand on these findings and identify other factors that facilitate and curtail productive use in other regions.

The potential livelihood benefits from the productive use of water, especially for women and poor households, can be significant. If the greater water quantities associated with multiple-use services (MUS) can be kept within the sustainable yield of watersheds, MUS presents a unique approach to realising the objectives of the 1992 Dublin Statement on Water and Sustainable Development. In this regard, the MUS approach presents a viable contender to the WASH paradigm, especially in rural and peri-urban areas where the productive use of water is prevalent.

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[11] The systems studied in Senegal can be defined as 'domestic plus' systems – i.e. they primarily provide water for domestic use, but make some accommodations for productive activties.

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APPENDIX

Table A1. *Selected system-level variables of interest.*

Variable	Description	All systems			
		N	Median	Mean	St. Dev.
Population served	Population served by the piped water system	47	3,879	4,882	4,291
Distance to road (km)	Mean distance to the nearest road from the central villages (km)	47	13	17	18
Distance to city (km)	Mean distance to the nearest city/major town from the central villages (km)	47	19	27	21
System length (m)	The combined length (m) of all system pipes (provides a measure of the size of the system)	47	8,649	13,979	15,841
System age (years)	Age of the water system	46	18	17	9
Water committee activities	Number of activities performed by the water committee (out of a possible 15 activities). These activities included items such as operating and maintaining the system, setting and collecting water	46	11	10	2.7

Variable	Description	All systems			
		N	Median	Mean	St. Dev.
	tariffs, keeping financial records, holding regular meetings with the community, and resolving conflicts among water users.				
Percentage of households attending WC meetings	Percentage of households that attended a water meeting in the last year	47	38%	38%	12%
Operator activities	Number of important activities performed by the operator (out of possible eight activities)	44	4	3.6	1.4
Operator satisfaction	Operator satisfaction with job (5=very satisfied, 4=satisfied, 3=neutral; 2=dissatisfied; 1=very dissatisfied)	44	5	4.4	1.1
Percentage of households that contributed to system	Percentage of households that made some sort of contribution (e.g. money, land, labour, material, and/or food for workers) towards the construction of the water system	47	19%	26%	24%
User ownership (perception)	Percentage of households that reported feeling ownership of the water system	47	86%	84%	10%
Percentage of households dissatisfied with water services	Percentage of households that reported being dissatisfied with their water services	47	60%	57%	27%
Percentage of households with national grid electricity	Percentage of households in each system with access to electricity from the central power grid	47	0%	14%	22%
LSU	90% trimmed mean of household livestock units	47	3.1	7.0	9.1
Index: Percent of system operational*	An index of the total number of operational components divided by the total number of installed components. An index value of '1' means that all of the installed system components were working at the time of the water committee interview. A value of '0.5' means that 60% of the system components were operational. The highest index value was 1 and the lowest 0.	46	0.995	0.899	0.225
Index: System breakdowns*	An index of the number of reported breakdowns in the past year from the household survey. An index value of '1' represents no breakdowns and '0' represents 11.5 breakdowns, the highest number reported. The highest index value was 0.996 and the lowest 0.	47	0.771	0.725	0.196

Variable	Description	All systems			
		N	Median	Mean	St. Dev.
Index: Duration of breakdowns*	An index of the time to fix a system breakdown as reported by household respondents. An index value of '1' represents no breakdown duration and '0' represents a breakdown lasting more than 30 days. An index value of '0.5' was set to represent a system breakdown lasting one week, which aligned with the median duration of system breakdowns of 7.64 days. A total of seven systems had an average breakdown duration longer than 30 days. The highest index value was 0.989 and the lowest 0.	47	0.486	0.472	0.288

* The index values were normalised to fit a 0 to 1 scale, where '0' signifies a poor level of piped water system performance and '1' signifies a high level of performance.

Table A2. Selected system-level categorical variables of interest.

Variable	Description		Number	Percent
Operator experience	Prior experience operating water system (none, some, very)	None	13	30
		Some	12	27
		Very	19	43
Community/ Externally initiated	The development of the piped water system was initiated by a community or external entity	Community	32	70
		External	14	30
Water conflicts	Reported water conflicts in village	Yes	5	11
		No	41	89
Aware before construction	Was the village aware that the water system would be installed before the construction began?	Yes	35	76
		No	11	24
External technical support	Has the water committee received unpaid external help with repairs or maintenance?	Yes	2	4
		No	44	96
External non-technical support	Has the water committee received external help with billing, accounting, payments or other administrative tasks?	Yes	4	9
		No	42	91
External financial support	Has the water committee received external financial support for operations and maintenance?	Yes	8	17
		No	38	83