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Sustainability of Rural Water Supply Systems: A Case Study of Kwamekrom Water System in the Volta Region of Ghana

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Abstract

This paper review and analyze the sustainability of rural water systems facilitated by Community Water and Sanitation Agency (CWSA) in Ghana in both their capacity to continue to deliver adequate, safe and quality water for all the people of Kwamekrom township and surrounding villages. The paper focus on a case study of the sustainability of small-town piped water systems; the main used technology in rural areas of the Volta Region in Ghana. Part of the project was the implementation of infrastructure and building capacities in the community to manage and use their system after project completion. A recent development is that CWSA is shifting from community ownership and management (COM) towards participation in management, a shift that is expected to ensure the sustainability of the water systems. The study aimed to analyze the viability of the Kwamekrom water supply system in the Volta Region of Ghana, which was under the COM system utilizing a survey mechanism. The study revealed based on performance indexes indicated that the Kwamekrom water system was not sustainable under the COM. The result was mainly due to poor financial management and lack of adequate technical expertise coupled with socio-political impact under the COM. The new reform towards participation in the management of rural water supply is, therefore, an approach which could lead to sustainability.

Keywords: rural water supply systems, sustainability, COM, CWSA

1. Introduction

The mission of CWSA is "CWSA is committed to facilitating the delivery of safe water and related sanitation services and hygiene promotion to rural communities and small towns." CWSA was established by an Act of Parliament, Art 564 in December 1998 in Ghana as a public sector organization and currently under the Ministry of Sanitation and Water Resources. CWSA, since its establishment, has been the frontline in facilitating and implementation of donor-funded low-cost water supply systems in rural areas for the provision of safe drinking water. For some reasons, there has been a lack of execution of specific evaluation on the effectiveness of these water projects; however, the huge budgets for these water projects should justify more particular assessment.

It is the target of the Millennium Development goal 7C to halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation; and also the Sustainable Development Goals (SDG) number 6 (SDG #6) targets the provision of affordable and reliable potable drinking water for all by the year 2030.

This paper provides this evaluation by using the sustainability of the water systems as a standard. The objective of this paper was to investigate the sustainability of the small town's water supply systems implemented by CWSA under COM. The approach to measure sustainability was addressed by administering research questionnaires based on:

- Definition of sustainability in this context and literature
- Practical measurement of sustainability of CWSA projects
- Performance evaluation of COM of the small town water systems

Sustainability of rural water supply systems is a significant development challenge in most developing countries, including Ghana. Measuring sustainability can help decision-makers to take relevant actions to mitigate the economic, social, and environmental impacts and reduce risks associated with the system in a systematic manner (Brandi *et al.*, 2017). A sustainable system is a system that can endure and maintain itself, but various disciplines of study may apply the term differently. Sustainability as a term has been used more in the sense of human sustainability on planet Earth and this leads us to the concept of sustainable development which is defined by the Brundtland Commission (Brundtland, 1987) of the United Nations (March 20, 1987) as follows: "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". The foundational challenges of sustainability are the lack of a standard definition of the term and the variations in synonyms that are used in the literature.

Theoretically, a system is sustainable if it continues to function after a prolonged period (Brikké, 2002. In: Cardona and Fonseca, 2003) or has the capacity for continuance (Parkin 2000a, b. In: Sohail *et al.*, 2005). Donors and government agencies focused on economic indicators of sustainability, civil society, and development institutions on the project, management, or social indicators while often users are mainly concerned about the flow of benefits and convenience. Though there is no consensus on the precise components of sustainability, it is widely agreed that any conception of sustainability must account for the interconnections of environmental, economic, and social factors (Milman and Short 2008). There are many factors that can influence the sustainability of water supply services (Whittington *et al*., 2008; Montgomery *et al*., 2009). The elements can be categorised as operational, maintenance, and management, which have been applied in this study. To measure the sustainability of small-town water systems facilitated by CWSA, theoretical sustainability in literature was compared with the performance of Kwamekrom system small town water system over the years. A framework of performance indicators was established for this analysis, which resulted in conclusions and recommendations about the sustainability of this small town water system. The mythology approach was qualitative with some elements of quantitative analysis of the limited mechanized piped water supply systems in the Volta Region of Ghana.

Despite efforts by the CWSA with support from donors and development partners to increase water coverage by providing new facilities and the rehabilitation of existing ones that have broken down, there has been a decline in rural water coverage in the region over the past two years from 63.50% in 2015 to 63.45% in 2016. The lack of access to safe drinking water by many people is an indication of the importance of sustainability. It is important to remember that a key consideration should be given to the efficient use of water resources to achieve sustainability.

2. Method

2.1 Description of Study Area

The study area was Kwamekrom which is located in the Biokoye district, which lies within longitude 00 15’ E and 00 45’ E and latitude 60 45’ N and 70 15’ N, in the Volta Region of Ghana (Figure 1). The District is well-drained by several rivers and streams, including Konsu, Bompa, Kabo, Ufuo, and Asukawkaw, some of which join the Volta Lake. The District falls within the Semi Equatorial Zone and experiences a bimodal rainfall regime that peaks in July and September for the major and minor seasons respectively. The mean annual rainfall is about 1,500 mm. The District experiences a dry season, which is characterized by the cool-dry North-East Trade Winds from early December to mid-March. Temperatures vary between 22oC and 34oC during the wet and dry seasons respectively.

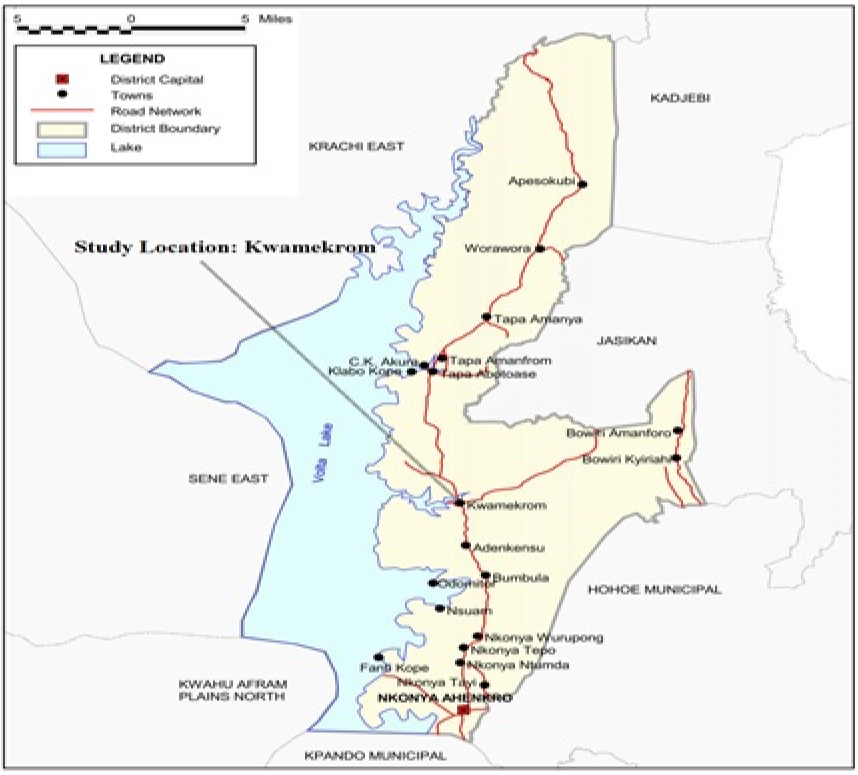

Figure 1. Location of Kwamekrom water supply system

2.2 Theory of Sustainability

The purpose of the sustainability theory, which can be divided into two partial goals, is to provide mathematical models that allow to measure sustainability and to provide guidelines for developing models. The term "sustainability" has been defined in journals from various technical fields, such as environmental science, management, and social science (Linton *et al*., 2007). Even though there are some common descriptions of sustainability in the literature, the concept is relatively new, and there exists a divergence of definitions of sustainability in existing research (Carter and Rogers 2008; Winter and Knemeyer 2013).

Various authors have defined sustainability and few are: Hockerts (1999) defined sustainability as any state of business in which it meets the needs of its stakeholders without compromising its ability also to meet the need in the future; Poter and Kramer (2006) defined sustainability as securing long-term economic performance by avoiding short-term socially detrimental and environmentally wasteful behavior; Gruen *et al.,* 2008 defined sustainability as the capacity of being maintained at a certain rate or level; Weiss (2000) define sustainability as a principle which states that economic growth (i.e., the generation of wealth) can and should be managed so that natural resources are used in such a way that the resource needs of future generations are assured. The measurement of sustainability in this context of the small-town water supply system is based on the characteristics of the community, management indicators, operational indicators, and maintenance indicators.

2.3 Sustainability Assessment

The methodology for the design of sustainability assessment models must include sustainability indicator and indicator aggregation formulations. The semantic or logical analysis of the terms sustainability and unsustainability leads us to unsustainability as the non-sustainability as the opposite concept of a complimentary class of sustainability, and this allows for the conceptualization from the approach of set theory in this respect (Alvira, 2017). The classic set theory allows for the first approach to sustainability and unsustainability as mutually exclusive concepts or indicators. This concepts or classes have empty intersection and union provides a universe of discourse. Take, for example, a class of all Adaptive Systems (AS) and divide it into two sub-classes will give:

- S or Sustainability to the class composed of all sustainable AS
- Likewise, we call ¬S or Unsustainability to the complementary class of S, composed by all

nonsustainable (unsustainable) AS.

$$S \cup \neg S = AS = \Omega\left[R\right] \tag{1}$$

$$S \cap \neg S = \varnothing^{20} \leftrightarrow S = 1 - \neg S \tag{2}$$

Therefore, if we divide all AS between S and ¬S, the union of both sets will include all AS, while its intersection will be empty. The disadvantage of this interpretation is that even though it is theoretically correct, it is too restrictive because it does not support classes which characterize most real systems

The analysis performed in this study was based on four performance indicators, namely the management performance, operational performance, maintenance performance, and hygienic operation performance. Their design is meant to combine various ways of monitoring into one system. The approach was used to obtain enough data on the performance of the water system for sustainability interpretation under COM. An appraisal of the performance was within the community, followed by an examination of the performance of the system through a design questionnaire survey by users and water board staffs.

2.4 Performance Framework

It is important for a comprehensive framework for adopting performance management of water supply systems in rural areas. It requires an integrated performance management framework and the development of models. The performance framework initiates with the identification of performance indicators based on a critical review must be based on analysis for the selection of performance indicators encompassing all the functional components. These performance indicators are then evaluated to deal with existing data limitations of the small town water systems. The performance indicators used were operation, maintenance, and management.

2.4.1 Operation (OP)

Operation refers to the routine activities and procedures that are implemented to ensure that the water supply system is working efficiently. A water system is operational when it is capable of supplying the volume and quality of treated; storage capacity; operators' operational knowledge and skill; and financial resources to support upgrades, materials, monitoring, and reporting. The rural water system operators must demonstrate that they can perform the administrative and technical operation tasks associated with the complexity of the water production and distribution system. An operating system must have highly trained personnel for pumping, water treatment, and water system technicians. The operators and technicians must participate in continuing education to ensure they are on the leading edge of water technology and regulations.

2.4.2 Maintenance (MT)

Maintenance refers to planned technical activities or activities carried out in response to a breakdown, to ensure that assets are functioning effectively, and require skills, tools, and spare parts (Carter, 2009). Maintenance of a water supply system is the management of the service that is needed to keep the system operational through proper planning and implementation. Maintenances are classified as either a corrective or breakdown maintenance, and preventive maintenance. Water supply systems should always ensure that an adequate level of preventive maintenance is scheduled for all of their assets. Preventive maintenance requires that adequately skilled persons are employed and provided with the proper tools. A strict and regular schedule of work is also required to ensure that preventive maintenance is executed without delay.

2.4.3 Management (MG)

Management of a water supply system requires financial responsibility and the institutional framework that is needed to keep the facility operational over a prolonged period. A Sustainable small-town water supply system should be able to provide adequate water quantity and appropriate water quality for consumption, without compromising the future ability to provide this capacity and quality. Management is the key to adequate water quality; fulfillment of budgets and reports; rectifying system deficiencies; acquiring operational permits; communication with regulatory agencies to resolve compliance issues, and updating equipment to save energy and reduce maintenance costs.

2.5 Collection and Classification of Data

The first data obtained was the general project and community characteristics. Other sources of information were obtained from baseline surveys and old project files. Old staffs and water board members were also interviewed because of their knowledge associated with the project and operations. The performance of the water system so far under COM was investigated within the community. A total of 50 people were interviewed in the community with prepared questionnaires. There were examinations like sanitary inspection and an examination of the water supply facility and records, leading to the determination of the various indicators.

The performance frameworks of indicators were divided into sub-indicators and sub-sub-indicators. The obtained information from the various sources was filled in the appropriate different sub-indicators. The sub-indicators were formulated such that the presence or workings out of the element have a positive effect on the sustainability of the project. To be able to make comparisons and interpretation of weak and strong points, for every sub-sub-indicator, a score range of 0 and 100% was contributed. The descriptions of the classifications are indicated in Table 1. The average scores of several sub-sub-indicators together form the rating of a sub-indicator., while the average scores of several sub-indicators form along with the result of an indicator. Averages were assigned without ascribing weight factors to the different elements. The indicators were assigned in a way that the same weight can be ascribed. The results were not intended to prove relations in the study.

Table 1. Classification of sub-sub-indicators

Assigned Scores (%)	**Classification**	**Interpretation**
0	Very bad	An absent or very bad element
25	Bad	An available, but bad element
50	Average	An average element
75	Good	A functional element, but need improvements
100	Very good	An excellent element

The interpretation of the various performance indicators was deducted based on the outcome of the different sub-sub-indicators and presented in Table 2. Note that it is in totally inconclusive to determine the base sustainability of the water system based on only these indicators considering many other external factors.

Table 2. Interpretation of results

Classification	**Grading of indicator and sub-indicator results**
0-25%	Unsustainable performance
25-50%	Small chance of sustainability, but not enough
50-75%	Higher chance of sustainability with improvements
75-100%	Sustainable performance

This study explored the possibility of sustainability assessment based on limited performance framework data by comparing sustainability in theory with the performance of the small town water supply system under the COM regime.

3. Results

3.1 History and Context

The Kwamekrom Water Supply System was one of the water supply schemes under the GTZ assisted project called EVORAP. The project began in 1995 under the then GWSC (now GWCL). The construction of the water system at Kwamekrom was completed in September 2006. At the time of the study, the community has a total population of 14,364, and within the Biakoye district of the Volta Region of Ghana. The system draws water from two (2) boreholes to serve the community. The components of the system include transmission pipelines (6,235m long), a high-level tank (HLT) of 120m^3 volume, and elevated 12m above the ground. There is a distribution system (16,887m) long of various pipe sizes) and 14 public fetching points (standpipes) with some household connections as well as institutional connections (32). Estimated water demand of 575m^3 was required daily in the Kwamekrom community.

The Kwamekrom water supply system at the time of study depends on only one borehole. The second borehole which was located in the flood plains of the Konsu river was flooded and had since been abandoned. The capacity for operation, management, and maintenance of the facility have been built for the community-based management teams in the beneficiary communities. However, over the years, it has been observed that the COM concept has not lived up to expectation. There are a number of challenges, including financial accountability issues, frequent breakdown of facilities, inefficient management of water systems, non-expansion of the water system to meet increasing demand, large unserved population, high levels of unaccounted (non-revenue) for water, poor or inadequate water quality monitoring, insufficient water supply for commercial uses in small towns amongst others.

3.2 Results of Water System Performance

The results on the performance of the Kwamekrom water supply system is summarised in Figure 2 below. The result indicated that the operation of the water system under COM was below average at 45% and the maintenance of the systems was inadequate at 25%. The management of the water system, which was the central part of any organization to sustain itself was a failure at 18%. This management indicator is the main reason for the unsustainability of the water system. The result could be the result of observed lack of training, capacity building for system staff under COM, and no supervision from donors and implementation authorities. There is also the factor of insufficient financial coaching, the inefficiency of tariff collection, and high non-revenue water losses. The results indicated that the COM regime is inadequately prepared to facilitate the sustainable management of the water system. The outcomes of indicators are discussed further below.

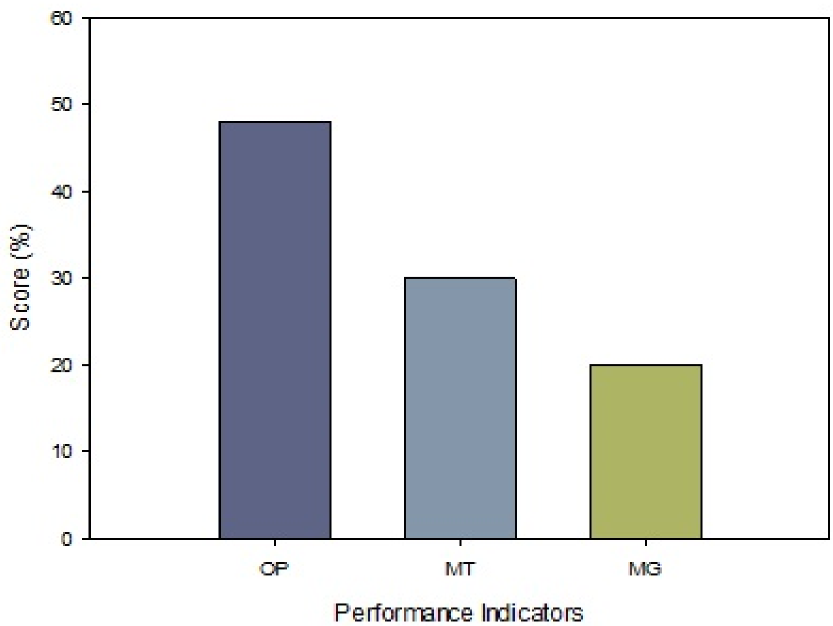

Figure 2. Results of performance with indicators for Kwamekrom water supply system

3.3 Water Quality

Water samples were collected from the source borehole (BH), from a standpipe (SP) in the community, and a household (HH) connection. They were sent to the laboratory and analysed for pH, Ca2+, Cl−, NO3, Fe2+, F-, Mn, K+. Most of the parameters were within the World Health Organization (WHO) guideline values for drinking water. Some parameters, however, were above recommended WHO standards. Figure 3 presents the water quality analysis data.

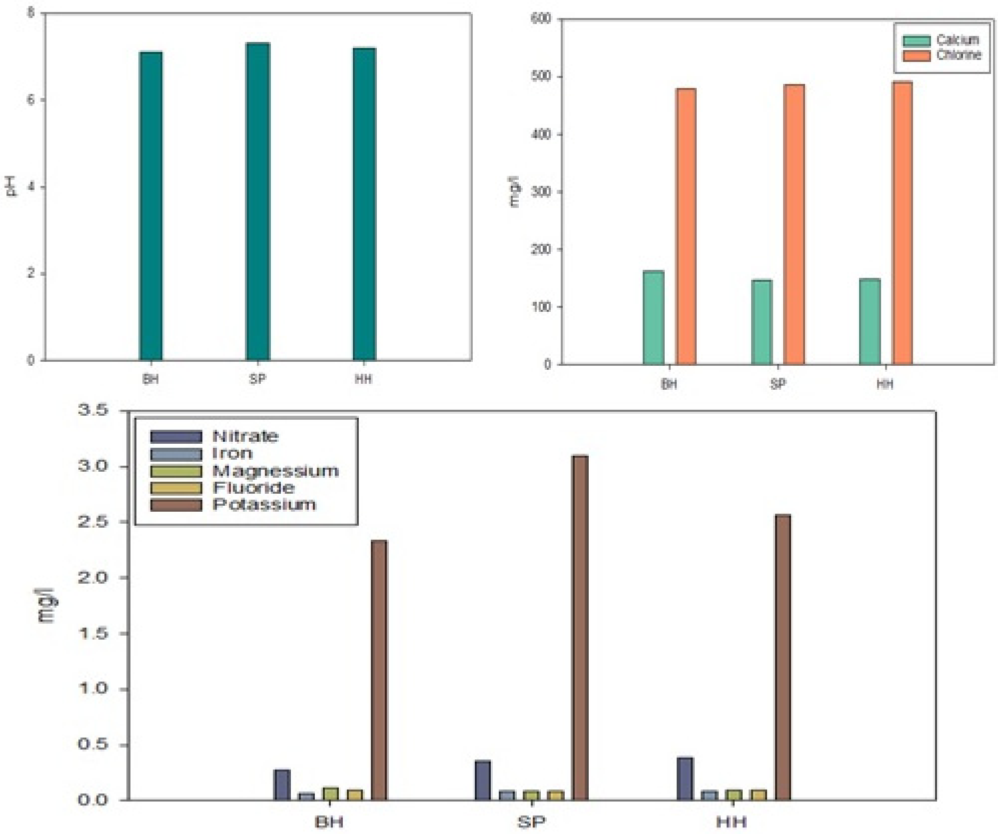

Figure 3. Measured water quality parameters from the Kwamekrom water supply system

4. Discussion

4.1 Operation (OP)

The study reveals that generally, the community was not satisfied with the service delivery of the water system under the COM. The water was not available all the time when needed, and only a few people do have household connections (32 households), while the majority of the community access water services from standpipe sales points distributed within the township. The customer's main problems of concern where the unreliability of supply and low pressure when there is supply, and brown colour of water during the rainy season. The brown colouration may probably be caused by high level storage tank not washed and flashed on time and leakages. Water quality and safety monitoring mechanisms are not available. Most of the standpipe has concrete structures in a dilapidated state and pools of water at the water fetching area.

4.2 Maintenance (MT)

From the study, it was clear the maintenance of the Kwamekrom water system was way below average. There were no funds and technical expertise to carry out maintenance services. There's also no money available to pay the most system staff for the past year for their work. Another weak aspect is the monitoring of the system. There was no assistance from external experts.

4.3 Management (MG)

The management of the Kwamekrom Water System under COM was limited to the collection of revenue from standpipe vendors and few connected households and recording. At the time of this study, there was no money in the bank accounts of the Kwamekrom water board under COM. The daily collection of revenue from standpipes and monthly collection of private connections were done by one revenue officer appointed by the water board. The efficiency of the collection is low, and only about 35% of the bills for domestic connections for the first quarter of 2018 have so far been collected. Standpipe vendors still have outstanding revenues unaccounted for and unpaid vendor commissions. The Kwamekrom water supply system cannot be called sustainable in this situation but can be improved for sustainability. The main setbacks are the operations and management of the water system. These setbacks could have been addressed by critical external monitoring of operations and management during and after project completion.

4.4 Water Quality

The chemical parameters of water are an indicator of its suitability as a source of water for human/livestock consumption and other purposes. Water quality assessment was carried out for some selected important parameters, although there is a need for a comprehensive water quality assessment. The results of the water quality analysis show that most of the parameters were within the WHO guide values for drinking water, with few above limits. pH ranges between 7.1 – 7.3 could be as a result of the geology of the area. Ca^{2+} was range 149 – 142mg/l above WHO standard of 75mg/l. The geology of the region is a factor contributing to the hardness of the water. Cl^- measured was in the range 477 – 492mg/l, a little above the WHO standard of 471gm/l and also a correlating factor to hardness. Measured Mn^{2+} range was 0.08 – 0.12 (WHO standard is 0.4mg/l), Fe^{2+} range was 0.8 – 0.1mg/l (WHO standard is 0.3mg/l), K^+ range was 2.3 – 2.7 (WHO standard is 5.1mg/l), NO_3 range was 0.2 – 0.4mg/l (WHO standard is 10mg/l), and F^- range was 0.08 – 0.1mg/l (WHO standard is 1.5mg/l). The water from the system is mostly good for potable use and needs improvement in terms of treatment.

4.5 Sustainable Performance

The assessment of the sustainability of the Kwamekrom water system based on literature definitions together with ascribed performance indicators formed the basis of the conclusion of this study. The study observed was that most (74%) of the problems were of maintenance (MT) and management (MG) and only a few (26%) had an operation (OP) background (Figure 4). The managerial setback was a major concern for the sustainable performance of the Kwamekrom water supply system under COM.

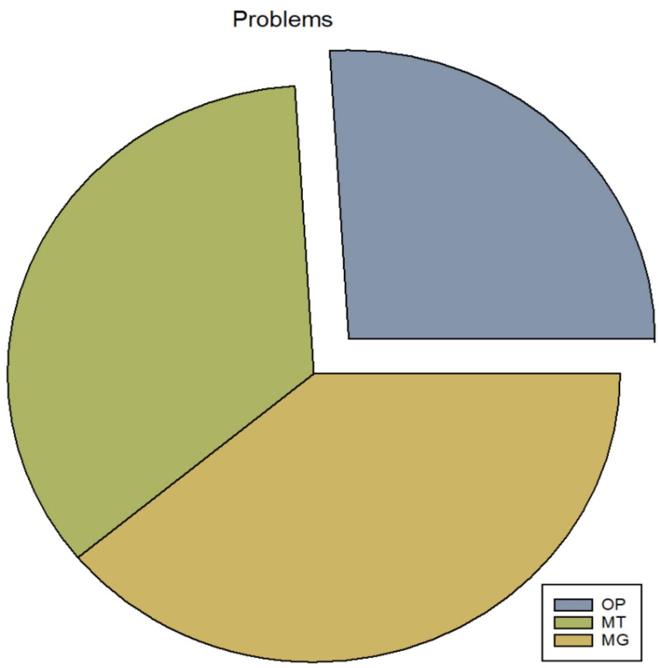

Figure 4. Distribution of OP, MT, and MG setbacks for the Kwamekrom water system sustainability

The approach of the study considered that limited data, interviews, and the available data were used to conclude and can be improved with comprehensive data acquisition methods and technology in further studies. In the Volta Region of Ghana, CWSA facilitates the provision of small-town water systems which are gravity water systems with groundwater sources. The sustainability of such one of these systems under COM was assessed by studying the sustainable performance of the Kwamekrom water system. The assessment indicated that the system under COM was not sustainable, although some elements of sustainability were there, which will require a lot of improvements. Poor management and lack of technical expertise were of significant concern with the water system functionality at about 50%, which could not be described as sustainable under COM. The implementation of reforms by CWSA to participate in rural water supply systems is an innovative approach. The change involves capital investment, employment of trained management staffs, and technical expected to manage these water systems. The water system staffs will be supervised at the regional and national level and supported by experts for older systems and new projects to be completed. Under the new regime, there is proper financial planning and budget, an appropriate tariff, agreements about the collection, monitoring points for facilities, plan of monitoring, and technical and technological advancement which will make these water systems sustainable and profitable. This approach by CWSA is an example which could be emulated by developing countries in Africa and beyond for effective, sustainable, and cost-effective management of rural water supply facilities.

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References

Brandi, H. S., dos Santos, S. F., & Sikdar, S. K. (2017). Measuring sustainable systems. In book: Reference Module in Earth Systems and Environmental Sciences. https://doi.org/10.1016/B978-0-12-409548-9.10046-6

Brikke, F. (2002). Operation and maintenance of rural water supply and sanitation systems: A training package for managers and planners.

Brikké, F., & Rojas, J. (2001, November) *Key-factors for sustainable cost recovery: in the context of community-managed water supply*. IRC International Water and Sanitation Centre.

Brundtland, G. H. (1987). Our Common Future: Report of the World Commission on Environment and Development. *Medicine, Conflict and Survival, 4*(1), 300.

Cardone, R., & Fonseca, C. (2003). *Financing and Cost Recovery*. IRC International Water and Sanitation Centre.

Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management: moving toward new theory. *International Journal of Physical Distribution & Logistics Management, 38*(5), 360–387. https://doi.org/10.1108/09600030810882816

Carter, R. C. (2009). Operation and Maintenance of Rural Water Supplies. In: Perspectives N° 2. St. Gallen: Rural Water Supply Network (RWSN).

Gruen, R., Elliott, J., Nolan, M., Lawton, P., Parkhill, A., & McLaren, C. (2008). Sustainability science: an integrated approach for health-programme planning. *Lancet, 372*(9649), 1579–1589. https://doi.org/10.1016/S0140-6736(08)61659-1

Hockerts, K. (1999). The SusTainAbility Radar. *Greener Management International*, (25). 29-49. https://doi.org/10.9774/GLEAF.3062.1999.au.00007

Linton, J., Klassen, R., & Jayaraman, V. (2007). Sustainable supply chains: An introduction. *Journal of Operations Management, 25*(6), 1075–1082. https://doi.org/10.1016/j.jom.2007.01.012

Milman, A., & Short, A. (2008). Incorporating resilience into sustainability indicators: An example for the urban water sector. *Global Environmental Change, 18*(4), 758–767. https://doi.org/10.1016/j.gloenvcha.2008.08.002

Montgomery, M. A., Bartram, J., & Elimelech, M. (2009). Increasing Functional Sustainability of Water and Sanitation Supplies in Rural Sub-Saharan Africa. *Environmental Engineering Science, 26*(5), 1017–1023. https://doi.org/10.1089/ees.2008.0388

Parkin, S. (2000a) Contexts and drivers for operationalizing sustainable development. In Sohail, M., ASCE, M., Cavill, S., & Cotton, A. P. (2005). Sustainable Operation and Maintenance of Urban Infrastructure: Myth or Reality? *Journal of urban planning and development, 131:1*(39), 39-49. https://doi.org/10.1061/(ASCE)0733-9488(2005)131:1(39)

Parkin, S. (2000b) Sustainable development: The concept and the practical challenge. In Sohail, M., ASCE, M., Cavill, S., & Cotton, A. P. (2005). Sustainable Operation and Maintenance of Urban Infrastructure: Myth or Reality? *Journal of urban planning and development, 131:1*(39), 39-49. https://doi.org/10.1061/(ASCE)0733-9488(2005)131:1(39)

Ricardo, A. (2017). *Mathematical theory of sustainability and sustainable development* (1st ed.).

Sohail, M., ASCE, M., Cavill, S., & Cotton, A. P. (2005) Sustainable Operation and Maintenance of Urban

Infrastructure: Myth or Reality? *Journal of urban planning and development, 131:1*(39), 39-49. https://doi.org/10.1061/(ASCE)0733-9488(2005)131:1(39)

Weiss, J. (2000). Sustainable Schools. In CEFPI Issue Track: 4.

Whittington, D. Davis, J., Prokopy, L., Komives, K., & Thorsten, R. (2009). How Well is the Demand-Driven, Community Management Model for Rural Water Supply Systems Doing? *Water Policy, 11*(2), 696–718. https://doi.org/10.2166/wp.2009.310

Winter, M., & Knemeyer, A. M. (2013). Exploring the integration of sustainability and supply chain management: Current state and opportunities for future inquiry. *International Journal of Physical Distribution & Logistics Management, 43*(1), 18-38. https://doi.org/10.1108/09600031311293237