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Sustainability Evaluation of Water Treatment Systems in Nine Cambodian Hospitals

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Bachelor of Science in Biology
Kent State University
2016

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An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
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Abstract

Sustainability Evaluation of Water Treatment Systems in Nine Cambodian Hospitals

By Erin Salvaggio

Background: Sustainable water, sanitation, and hygiene (WASH) services in health care facilities (HCFs) are critical for providing safe, quality healthcare. The Sustainable Development Goals (SDGs) set in 2015 demonstrate the motivation to expand the scope of safe WASH from the traditional home setting to also include institutions such as HCFs. The General Electric (GE) Foundation donated nine decentralized water treatment systems to nine hospitals in Cambodia. There is a need to assess the sustainability of these systems in order to guide evidence-based decisions on policy and investments for more effective and efficient interventions for WASH in HCFs.

Objective: A rigorous sustainability evaluation was conducted in order to provide a deeper understanding of the environment needed to sustain access to, and provision of, safe water at Cambodian hospitals operating GE water treatment systems.

Methodology: An explanatory mixed-methods study design was conducted using surveys, water quality testing, and observations. Data collection activities occurred three times between 2015-2019 to assess the change in sustainability over time. Scores were calculated using the Safe Water Sustainability Metric (SWSM) and ranged from 0 to 4 in four sustainability domains: technical feasibility, on-site capacity, accountability, and institutional engagement. Following the SWSM assessment in 2019, in-depth interviews were conducted with leadership from four case study hospitals to understand what affected the sustainability outcomes.

Principal Findings: Five out of the nine systems were no longer functional or used at the time of the 2019 assessment. Major barriers to sustainability included: lack of access to major repair parts, staff turnover and lack of trained staff for operation and maintenance, lack of repeated training on how to operate and maintain the system, and a lack of satisfaction and commitment by the hospital director. Major enabling factors included: dedicated staff for operation and maintenance, source of internal funding for operation and maintenance costs for the system, and satisfaction and commitment by hospital director.

Conclusion: The SWSM effectively identified the key limiting and enabling factors within the sustainability domains and these findings can be used to inform future interventions and trainings. Furthermore, this information can help fill the gaps in knowledge for sustaining access to and provision of safe water in HCFs in LMICs.

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Introduction

Sustainable water, sanitation, and hygiene (WASH) services in health care facilities (HCFs) are critical for providing safe, effective, accessible, efficient and equitable healthcare [1]. Quality WASH infrastructure is needed so patients are motivated to seek care from HCFs and so that once there, patients are able to receive safe healthcare. Patient dissatisfaction with poor WASH provision in HCFs has been associated with a delay in patients seeking healthcare, which subsequently leads to significant morbidity and mortality [2]. Additionally, efforts to control the spread of disease within HCFs are severely hampered by limited WASH services due to lack of disinfecting and handwashing. HCFs need improved WASH coupled with infection prevention control (IPC) strategies in order to effectively mitigate spread of health care-acquired infections (HCAIs). Yet, while it is evident WASH infrastructure in HCFs is critical for patient care, there is limited research on what contributes to a sustainable environment for the provision of safe water in HCFs. As such, this thesis aims to examine the sustainability of water filtration systems that were donated to HCFs in Cambodia.

Appropriate WASH services, such as availability of safe water, are a core component of effective IPC programs at HCFs. Lack of such services prevents the successful implementation of IPC practices which puts the health and safety of health care workers, patients, and at high risk [3]. Unsafe water poses a hazard for infection, promoting pathogenic microbial growth and serving as a source for HCAIs. In 2011, the World Health Organization (WHO) reported that on average 15% of patients in low-and middle-income countries (LMICs) suffer from at least one HCAI at any given time, with attributable mortality estimated at 10% [4]. It is the responsibility of senior level management and local authorities to ensure that WASH provision is to the level of service that allows for a safe and hygienic environment to reduce the incidence of HCAIs, thus improving health outcomes at that HCF [3].

The Sustainable Development Goals (SDGs), set by the United Nations World Assembly in 2015, demonstrate the motivation to expand the scope of safe WASH from the traditional home setting to also include institutions such as HCFs, schools, and refugee camps by highlighting universal and equitable access in SDG 6. With this momentum for WASH in HCFs, more interventions and infrastructure are being implemented and built. However, the current WASH delivery strategies and approaches that many governments and development partners practice may not be effective in achieving these SDG goals. UNICEF and the wider WASH sector recognize that the acceleration, scalability, sustainability, and equity of WASH service delivery requires a paradigm shift in thinking and implementation [5]. Long-term systemic changes required for WASH provision in HCFs, such as accountability mechanisms and management systems, are currently not prioritized, but once national standards are developed for WASH in HCFs, sustainability is more likely to be achieved [6].

Although the WHO to date has pinpointed barriers to providing WASH in HCFs, there is limited research around what contributes to a sustainable environment for the provision of safe water. It is recognized that staff in HCFs are given no incentives or training on how to improve and manage their WASH services, and many countries lack standards for WASH in HCFs. When standards do exist, lack of funding and motivation hamper implementation [5]. More research within the scope of sustainability and WASH in LMIC's is needed to help strengthen policy and support investments in more effective and efficient interventions and strategies for WASH delivery in HCFs.

Literature Review

Health Care – Acquired Infections: Global Burden and Significance in Cambodia

HCAIs constitute an important health challenge worldwide and pose a major threat to patient and health worker safety. HCAIs are deemed the most frequent complication threatening patients' health [3,10], with approximately 7% of patients in high-income countries and 10% of patients in low-income countries acquiring at least one HCAI throughout their life [11]. The true global burden of these infections remains unknown because many LMICs lack a national surveillance system making it difficult to project global estimates of HCAIs [12,13]. Because of this, HCAIs may constitute an even bigger global health challenge.

The provision of WASH services in HCFs serves to prevent infections and spread of disease, protecting both staff and patients. As part of *WHO's Guidelines on Core Components of Infection Prevention Control Programs*, appropriate infrastructure, including the health care facility building and the availability of safe water, are essential requirements of proper IPC [4]. Primary HCFs in rural areas are frequently the first point of care, yet without proper WASH services, the ability of health care workers to practice proper IPC measures is severely hampered. A 2019 study found that improvements in water quality and access can reduce mortality of mothers and neonates in LMICs due to HCAIs when paired with improved IPC practices of the health care workers [14].

HCAIs are significant health problems in HCFs in Cambodia. A prospective HCAI surveillance study was conducted in 2015 in a Cambodian pediatric referral hospital and found that the incidence of HCAIs was 4.6/1000 patient days [15]. HCFs can adopt strategies that are readily available and inexpensive in order to combat the burden of HCAIs. These strategies include adhering to good hand hygiene practices and wearing gloves, soaking and cleaning instruments and other items followed by sterilization, improving the environmental cleanliness in operating rooms, and safely managing healthcare waste [16].

In 2010, the Ministry of Health in Cambodia released *Infection Prevention and Control Guidelines for Health Care Facilities*, that described a comprehensive IPC program that included every level of the healthcare system. The major components of this program were to provide IPC education and training, provide the necessary infrastructure for IPC, and data collection for HCAI surveillance [16]. This report also included guidelines for water infrastructure and advised that all HCFs must have a safe, adequate water supply free of physical microbiologic pollution [16].

Global Access to Safe Water

Access to safe water is closely related to the health outcomes of a country. Absent, inadequate, or inappropriately managed water can expose individuals to preventable diseases, particularly in health care settings where both patients and staff are at risk for HCAIs [3,15]. When a HCF has poor WASH provision and compromised IPC practices, a cascade of consequences follows. An increased risk of HCAIs leads to an overreliance on preventive use of antibiotics, and an increased rate of HCAIs leads to higher healthcare costs. Addressing these challenges requires joint efforts to improve both WASH and IPC in healthcare settings [17].

The WHO/UNICEF Joint Monitoring Program (JMP) produces regular estimates of national, regional, and global progress on drinking water, sanitation and hygiene. The indicator used by JMP to assess global access to safe drinking water is the percentage of the population using “safely managed drinking water services”. In order to meet the criteria for a “safely managed drinking water service”, people must be using a source that is accessible on the premises, the water should be available when needed, and the water supply is free from contamination [18]. The service ladders described by the JMP allow for a comparison of progress towards SDG 6. The drinking water service ladder is built on the established improved/unimproved water source classification. An improved drinking water source is defined by the nature of its design and construction to deliver safe water [19]. Table 1 further explains the levels of service within the JMP ladder for drinking water.

Table 1: JMP Drinking Water Service Ladder [19]

Safely Managed	Drinking water from an improved water source which is located on premises, available when needed and free from fecal and priority chemical contamination
Basic	Drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queuing
Limited	Drinking water from an improved source for which collection time exceeds 30 minutes for a roundtrip including queuing
Unimproved	Drinking water from an unprotected dug well or unprotected spring
Surface Water	Drinking water from a river, dam, lake, pond, stream, canal, or irrigation canal

A 2014 study concluded that an "improved source" provides a measure of sanitary protection but does not ensure water is free of fecal contamination [20]. The quality of safe drinking water may vary between countries and regions, since no single approach to sustained water provision is universally applicable. Therefore, WHO developed a framework for determine whether or not a drinking water source is 'safe' in their *4th edition of Guidelines for Drinking-Water Quality*. The framework is comprised of health-based targets, guidance on what is needed for adequate and properly managed systems (infrastructure, monitoring, planning, and management), and surveillance for disease. In addition, the WHO highlights microbial, chemical, radiological, and acceptability aspects that support the framework for safe drinking water [21]. Fecal indicator organisms, such as total coliforms and *Escherichia coli* (*E. coli*), are used as the primary measures of microbiological water quality in both high- in both high- and low-income countries.

Indicator organisms are used as indicators of fecal pollution, the effectiveness of treatment (filtration and/or disinfection), and the integrity and cleanliness of distribution systems. Total coliform bacteria include both fecal and non-fecal species and are most widely used as an indicator for treatment efficacy. *E. coli* are excreted by humans and animals, and as a result are used as indicators of fecal contamination of water. Higher concentrations of *E. coli* in water are interpreted as reflecting greater risk of the presence of fecal pathogens. Both total coliforms and *E. coli* concentrations are expressed per 100mL, and the WHO Guidelines recommend <1 Most Probable Number (MPN) per 100mL of these indicators in drinking water [21].

In addition to indicator organisms, free chlorine residual should be assessed when chlorine is added to water as a disinfectant. The presence of free chlorine residual in drinking water indicates that a sufficient amount was added to the water to inactivate most of the harmful organisms, and the water is protected from recontamination during transportation and storage (typically 4-24 hours). The Centers for Disease Control and Prevention (CDC) recommends between 0.2 - 2.0 mg/L of free chlorine present to ensure that the water does not have an unpleasant taste or odor but still has sufficient residual to protect from recontamination [22]. It is also recommended that other treatment methods such as filtration occur before chlorine treatment because chlorine-resistant microorganisms and turbidity can lower the effectiveness of the chlorine treatment [22].

Water Systems

Centralized water systems are able to deliver potable water to large populations when they are protected and maintained. Unfortunately, many centralized systems around the world are ageing, stressed, and poorly maintained [23]. Failures in centralized water systems, such as loss of adequate disinfectant residual, low water pressure, intermittent service, and ageing infrastructure can result in declining quality of the water supply. Additionally, pathogen intrusion may occur under these circumstances if poor sanitary conditions exist [24]. Although some HCFs in rural areas of Cambodia are connected to a piped water supply from an improved source, there is a risk of contamination because water flow may be intermittent, and the infrastructure may be substandard.

Studies have shown that low-cost, on-site water treatment systems, such as solar disinfection, chlorination, and slow sand filtration, have improved the microbial quality of drinking water at the household level in low-income countries [25,26]. Since Cambodia has sufficient water resources, the potential for water treatment using point-of-use (POU) filtration is high. A 2010 study conducted in Cambodia found that water treatment using POU filtration at the household level was effective for removing microbial contaminants, but interviews with households concluded that ownership of a filter did not imply proper use. Additionally, lack of knowledge and apathy toward the filter minimized its benefits [27].

On-site water treatment systems can also be utilized at an institutional level. When coupled with an adequate water supply, on-site treatment can provide high quality water in volumes suitable for institutions such as schools and HCFs [28]. On-site water treatment systems using ultrafiltration membranes have a growing potential for use in low–income settings since the costs of these systems have decreased rapidly. Additional benefits of membrane filtration compared to conventional water treatment (chlorination, slow sand filtration, etc.) include treatment of raw water in one step with or without the addition of chemicals, decreasing membrane costs, decreasing energy requirements with technology improvements over time, and flexible design for diverse systems [29]. Although membrane technology comes with many advantages, there are some associated challenges such as membrane fouling prevention can be expensive in both time and supplies. Furthermore, backwashing and chemical cleaning is necessary as part of regular equipment maintenance and is completed manually [25,29]. However, many HCFs lack the appropriate monitoring mechanisms to ensure daily tasks are being completed. More research is needed to understand how the knowledge, attitudes, and practices of leadership at institutions who receive filtration systems are associated with the sustained operation, maintenance and use of the systems.

WASH in Healthcare Facilities

The SDGs adopted in 2015 aim for ‘universal access’ to WASH services, which calls for a greater emphasis on increasing access to safe drinking water beyond the home by also including institutional settings such as schools, HCFs, and workplaces. SDG 6 specifically addresses the goal “to ensure availability and sustainable management of water and sanitation for all” by achieving the following targets [30]:

6.1 Achieve universal and equitable access to safe and affordable drinking water for all

6.3 Improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemical and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

Targets 6.1 and 6.3 will directly affect safe water provision in HCFs by ensuring interventions are providing safe water at the institutional level. In 2019, the JMP published the first global assessment of water, sanitation, hygiene, health care waste management and environmental cleaning services in HCFs, providing a baseline for future monitoring efforts. This assessment utilized a set of indicators and questions developed by JMP to monitor for WASH and related IPC measures. The assessment found that globally, 74% of HCFs have access to a basic water source, 14% have limited access, and 12% have no access [31]. The JMP database includes estimates for the progress of WASH in HCFs since 2000, but this report concluded that WASH services in HCFs are sub-standard in every region.

While the JMP database encompasses data from over 100 countries and aggregated into households, schools and HCFs categories, there are large gaps in Cambodia's WASH in HCF data [32]. In a 2017 survey of 117 HCFs in Cambodia (101 health centers and 16 referral hospitals), 91% had access to an improved water source on the premises, but only 49% of these facilities had enough water year-round [32]. Additionally, only 6.2% of referral hospitals had functional hand hygiene stations available at all critical points of care and within 5m of toilets, and only 12.5% had safely segregated healthcare waste [33]. The key challenges that were identified included a lack of leadership and knowledge of WASH at the facility level and a lack of formal coordination mechanisms for WASH in HCF targets between the health and WASH sectors. Moreover, many HCFs must rely on unimproved sources for water shortages during the dry season [33]. These findings suggest that there is much room for improvement for WASH in HCFs in Cambodia, and there needs to be coordination between health and WASH actors, as well as capacity development within the areas of water systems maintenance and sustainability.

Barriers and Facilitators to Sustainability of WASH Systems in Healthcare Facilities

The importance of sustainability has become widely acknowledged in the WASH sector, with a growing emphasis. WASH projects often focus on providing basic infrastructure, rather than ongoing functionality [34]. Further, human and financial capacity and needs are often overlooked the sustainability of these projects is actually assessed [35]. According to a report published by Improve International NGO, it is estimated that anywhere between 30 and 60% of existing water supply systems do not provide adequate service [36]. Capturing the complexity of sustainability has proven to be challenging, and exact definitions vary. One definition of sustainability for a WASH intervention involving the installation of infrastructure is “the degree to which the device is serviceable with locally available materials and does not cause significant harm to the environment in either production or daily operation” [37], but the definition does not capture the quality of WASH service provision.

As of recently, there has been emerging research that has identified facilitators and barriers to WASH sustainability. A 2011 sustainability evaluation of a WASH intervention in schools identified six enabling environment domains for sustainability: financial capacity, accountability, technical feasibility and availability, community support, school leadership and management, and student engagement [38]. The six enabling environment domains identified in this study, along with other studies, have identified similar enabling factors for the sustainability of WASH interventions, and emphasize that these can be used as proxy indicators when assessing WASH sustainability in institutional settings. [9,38]. The studies have also identified barriers to sustainability, such as a lack of funds to purchase water treatment replacement parts and soap, and a lack of funds for repairs. Furthermore, system breakages, incorrect chlorine dosing, poor access to repairs and replacement parts, and a lack of prioritization and motivation for WASH were also highlighted as barriers to sustained WASH in institutions

Studies specific to on-site membrane filtration systems in HCFs in low–income settings have found unique facilitators and barriers to sustainability. Equipment, installation design, construction quality, and response time to resolve interruptions due to equipment failure influence water purification and technical performance of the system. Availability and capacity of health center personnel to perform routine operation and maintenance of the system were identified as organizational factors that influence system performance. Lastly, availability of water and power, and public infrastructure related to water and power to the HCF were identified as environmental determinants of performance [37].

Since sustainability has emerged as an important focus in the WASH sector, multiple tools have been developed for monitoring and evaluating WASH interventions. Some tools were designed for very specific conditions such as technologies being used, whereas other tools produce outputs that could be used for a variety of different WASH stakeholders. A 2013 study compared 25 tools that have been utilized to assess sustainable WASH interventions. The tools were developed by different types of organizations, for different target audiences, and with different objectives. The most common target audience was implementing organizations (37%), followed by donors (23%), and national government (19%). Collectively, these tools have been used 92 times in 52 countries around the world, however almost half of the tools were developed for African countries [39]. The tools measured similar sustainability domains that each of the tools measured which included, institutional management as the most common, followed by technical areas, financial, environment, and socio-cultural. Additionally, the focus of most of the sustainability tools identified was on the sustainability of the full project/program, rather than the sustainability of the WASH technologies being used [39].

Community- and school-level tools are inadequate to evaluate the sustainability of WASH interventions in HCFs due to the complex needs for different healthcare water uses, as well as the vulnerability of the people using the water [9]. Although there are tools to assess WASH conditions in HCFs, such as WASHCon and WASHFIT, these tools do not measure sustainability, but rather the current state of WASH. Researchers at the CGSW designed the Safe Water Sustainability Metric (SWSM) tool to address this measurement gap. This tool examines four domains of sustainability: Technical feasibility, on-site capacity, financial and operational accountability, and institutional engagement [9].

There are several policy implications for the use of sustainability tools in the WASH sector. Most importantly, making the outputs of the tools available to permanent stakeholders, such as local and national governments is crucial for more impactful and scaled up interventions. When used on a routine bases, these tools have the ability to strengthen monitoring systems at every level and provide guidance for more sustainable approaches to WASH interventions.

Research Context

General Electric Foundation and Provision of Safe Water in HCFs

Organizations such as General Electric Foundation (GEF), The Center for Global Safe Water, Sanitation, and Hygiene at Emory University (CGSW), and WaterAid Cambodia recognize the importance of being a part of recent momentum for improved and sustained WASH in HCFs and have sought to address these issues. GEF is the philanthropic branch of General Electric Corporation and focuses on increasing access to quality healthcare in underserved communities around the world. GEF currently works in four program areas - Developing Futures™, Developing Skills, Developing Health Globally™ (DHG), and Developing Health U.S. - where it collaborates with national ministries of health, public and private health facilities, non-governmental organizations, and academia in order to build sustainable solutions for some of the world's most pressing global development issues [7].

The DHG program focuses on interventions in 16 countries in sub-Saharan Africa, Latin America, and South Asia. Since its founding in 2004, the DHG program has impacted over 300 HCFs by focusing on: Safe Surgery, Maternal and Child Health, Leadership, and Disaster Relief [8]. Providing safe water has been a main focus within this program with the donation of on-site water filtration systems to hospitals and clinics in several countries, including Cambodia.

In 2015, General Electric water filtration systems were installed in nine referral hospitals in Cambodia. The goals of this GE project were to upgrade infrastructure and install water filtration systems in the nine hospitals, train hospital staff on maintenance of the system, and train hospital staff on WASH in HCFs as it relates to IPC. The CGSW study team was responsible for conducting baseline assessments of the hospitals that received a water treatment system donation, monitoring the performance and use of the systems, and evaluating the sustainability of the water filtration systems over time. Data was collected over three rounds from 2015 – 2019 (baseline, midline, and endline) using the systematic tool, Safe Water Sustainability Metric Tool (SWSM), designed to assess the sustainability of safe water provision in HCFs. In this context, sustainability was measured by examining four domains: technical feasibility, on-site capacity, financial and operation accountability, and institutional engagement [9]. Near the end of the study in 2019, hospital leadership's attitudes, knowledge, and practices towards the systems were also assessed qualitatively using key informant interviews.

Problem Statement

GEF provided nine hospitals in Cambodia with effective water filtration systems for safe water supply. However, there is a need to understand whether these systems were able to be sustained and the barriers and facilitators of sustainability in this context.

Purpose

The purpose of this study was to conduct an in–depth evaluation of safe water sustainability in nine hospitals that received GE water treatment systems in order to provide a deeper understanding of the barriers and facilitators to the sustainable provision of safe water. Findings from this study will help inform the wider WASH sector on the different factors that may contribute to an enabling environment for sustainable water filtration systems in HCFs.

Research Objectives

This study seeks to achieve the following research objectives:

Objective 1 – Assess the sustainability of safe water provision at each study hospital over the course of four years as it relates to four domains of sustainability: Technical Feasibility, On-Site Capacity, Financial and Operational Accountability, and Institutional Engagement.

Objective 2 – Assess the water quality at the nine hospital sites over the project period.

Objective 3 – Determine how the knowledge, attitudes, and practices of hospital leadership contribute to the sustainability of the treatment systems.

Research Questions

Research Question 1 *- Were the GE on-site water filtration systems sustainable in the nine hospitals in Cambodia?*

1a. How did each hospitals' sustainability domain and sub-domain scores change over the course of the project?

Research Question 2 *– Did the water quality from the systems meet WHO drinking water standards consistently throughout the project period?*

Research Question 3 *- What were the barriers and facilitators to the sustainability of the GE water treatment systems?*

3a. How are the attitudes, knowledge, and practices of leadership at the hospitals associated with the sustainability outcomes?

Significance Statement

Understanding the barriers and facilitators to sustainability of the on-site water filtration systems will help improve future implementation of water treatment systems within healthcare settings, as well as inform the wider WASH sector on the appropriate environment, training, and support needed when implementing such projects. When HCFs have sustained access to a safe water supply, patient satisfaction, quality of care, and health outcomes associated with these facilities are likely to improve.

Methods

Study Setting

Nine hospitals in Cambodia where the GEF donated GE water filtration systems were selected as study sites (Figure 1): Koh Thom, Baray Santuk, Kampong Thom, Sampov Lun, Thmar Kol, Kampong Tralach, Oudongk, Bun Rany Hun Sen and Kampong Trach. These hospitals were selected by the Cambodian Ministry of Health, GEF, CGSW, and Assist International for inclusion in the donation program based on certain criteria, such as reliability of the power and water supplies, the availability of at least two staff members to maintain the water treatment system, the hospitals' commitment to paying the operating costs of the system, and a hospital director who was motivated to provide safe water. As a result, the selected hospitals are not representative of the majority of government-run HCFs in Cambodia or in other LMICs. Each hospital is a district-level government referral hospital and located in a range of geographic locations, with some close to the capital city and others were in more remote areas. All nine hospitals provided maternal and child health services, surgical care, and some offered additional services such as eye and dental care. All have a medical laboratory and pharmacy. Demographic data on each hospital is presented in Table 2.

Figure 1: Map of Study Hospital Sites

T**able 2:** Hospital Demographics

Hospital	Inpatient Beds	Outpatients per Month	Deliveries per Month	Clinical Staff per Day
Baray Santuk	70	1400	122	60
Kampong Thom	120	923	45	46
Koh Thom	74	238	61	118
Kampong Trach	75	1200	12	38
Oudongk	40	N/A	40	30
Kampong Tralach	28	40	55	42
Thmar Kol	48	700	65	38
Sampov Lun	65	269	58	47
Bun Rany Hun Sen	40	925	65	26

Overview of Data Collection Activities

An explanatory mixed – methods research design was used to evaluate the sustainability of the water filtration systems in the nine selected hospitals in Cambodia. The Safe Water Sustainability Metric (SWSM) [9] was used as the main evaluation tool and identifies specific areas of sustainability in which a hospital demonstrated excellence or areas of improvement. When the assessment results are shared with the hospital staff, the stakeholders are informed about the next steps needed to improve the water filtration systems and they are also provided evidence for what an enabling environment for sustainability looks like. This metric was specifically designed for this GEF donation project and is based on the scientific literature and its previous use at other GEF donation sites, and it is explained in more detail below.

Researchers from CGSW at Emory University created The Safe Water Sustainability Metric in order to assess the sustainability of safe water provision in HCFs. The SWSM was developed in two iterations. The first version was used in hospitals in Honduras (4) and Ghana (6) that had received GEF donations of water filtration systems. Based on lessons learned about the sustainability of water systems in these hospitals, the SWSM was revised into a version that is applicable to HCFs of various sizes, using various water treatment technologies in a range of settings. The revised version of the SWSM was used in this study [9].

In this study, the SWSM assessment was conducted at each study hospital two or three times during the study period. This tool employs three methods: multiple interviews with hospital staff leadership, observation checklists, and microbial and chemical water quality testing. The surveys and observations were collected using a mobile device using CommCare (Dimagi Inc, Cambridge, MA), an open-source mobile data collection platform [9]. Data collection was conducted three times during the project period: baseline – 2015/2016 at all nine hospitals, midline – 2017 at 8 hospitals (excluding Bun Rany Hun Sen Hospital), and endline – 2019 at 8 hospitals (excluding Baray Santuk Hospital). The exact timeline for data collection activities for each hospital is presented in Figure 2. The number of hospitals assessed varied at the different data collection points due to the availability of the hospital director and staff to participate in surveys. Additional in-depth interviews were conducted with four hospital directors in 2019 to further explore why some hospitals performed well on the SWSM and others did not.

	Jul-15	August	September	October	November	December	Jan-16	February	March	April	May	June	July	August	September	October	November	December	May-17	June	Feb-19	March	April	May	June	July
Baray Santuk	X	X	X	X	X	X	X	XO	X	X	X	X	X	X	X	X	X			XO						X
Kampong Thom	X	X	X	X	X	X	X	XO	X	X	X	X	X	X	X	X	X			XO		XO				
Koh Thom	X	X	X	X	X	X	X	XO	X	X	X	X	X	X	X	X	X			XO			XO			
Kampong Trach						X	X	XO	X	X	X	X	X	X	X	X	X			XO			XO			
Oudongk						X	X	XO	X	X	X	X	X	X	X	X	X		XO				XO			
Kampong Tralach						X	X	XO	X	X	X	X	X	X	X	X	X			XO			XO			
Thmar Kol						X	X	XO	X	X	X	X	X	X	X	X	X		XO		XO					
Sampov Lun						X	X	XO	X	X	X	X	X	X	X	X	X		XO		XO					
Bun Rany Hun Sen						X	X	XO	X	X	X	X	X	X	X	X	X						XO			

Figure 2: Data Collection Activities July 2015 – July 2019

* X – Water Samples

** O – Surveys and Observations

SWSM Tool Sustainability Evaluation

Hospital Staff Surveys

Surveys were conducted with the HCF director (46 questions), the maintenance person in charge of the water filtration system (40 questions), and 2 HCF staff (11 questions posed to both clinical and non-clinical staff) at each hospital who were selected by convenience sampling. The surveys were administered orally in Khmer by a research assistant, and responses to each question were recorded on a mobile device. The surveys consist of closed – ended questions that pertained to the four domains of sustainability assessed by the SWSM: technical feasibility, on-site capacity, financial and operational accountability, and institutional engagement.

Water Tap Observations

Water tap inspections at each hospital were conducted by the researchers in order to assess the wards' access to water. The inspections consisted of structured observations of the water taps in the same seven wards at each hospital: Pediatrics, Labor and Delivery, Surgery, Pharmacy, Laboratory, Outpatient, and Kitchen. These wards were chosen based on the vulnerable populations they serve, and the critical need for water to execute daily operations. Each water tap was tested for functionality by the observer turning on the water tap and recording whether or not water flowed from the tap without having to make any adjustments to get the water flow.

Water Quality Testing

During Project Period – June 2015- November 2016

In order to assess the water quality provided by the on-site treatment system, monthly water samples were collected from each study hospital and tested for *E. coli*, total coliforms, and chlorine residual. An average of ten water samples were collected from each hospital from specific wards, such as the maternity, surgery, pediatrics, outpatient, and the hospital lab. Monthly water samples were collected from June 2015 to November 2016 for three of the study hospitals (Koh Thom, Baray Santuk, and Kampong Thom) and from December 2015 to November 2016 for the remaining six hospitals (Thmar Kol, Kampong Tralach, Oudong, Bun Rany Hun Sen, Kampong Trach, and Oudong). Sample numbers per hospital varied based on the number of wards and water availability. Samples were collected in 100mL Whirl-Pak bags containing sodium thiosulfate to neutralize chlorine before microbiological analysis. Samples were transported on ice to a single laboratory set up by researchers and processed within eight hours of collection. The undiluted water samples were analyzed with the IDEXX Quanti-Tray/2000 system for total coliforms and *E. coli* using the Colilert-18 reagent (IDEXX, Westbrook, ME). Total coliforms were selected as indicators of the efficacy of the water treatment system. *E. coli* was selected as an indicator for recent fecal contamination and risk for waterborne disease [21]. Microbial concentrations were estimated using the most probable number (MPN) method where the lower and upper detection limits were <1 and 2419.6 MPN per 100mL. Total and free residual chlorine were analyzed using a digital colorimeter (DPD method, HACH, Loveland, CO). Water samples were collected and processed by two members of the CGSW research team.

Post-Project Follow-up Assessment

An average of seven water samples were collected from different points of use within the nine hospitals during a single collection visit between February 2019 – May 2019. Samples were collected in 100mL Whirl-Pak bags containing the Aquagenx growth medium [40]. This was then poured into the Aquagenx compartment bags and incubated at ambient temperature for 24 hours.

This method was used for endline data collection due to logistical and resource constraints. *E. coli* results were calculated based on the Aquagenx color-match scoring system [40]. The MPN table has risk categories of drinking water based on categories of *E. coli* levels: 0/100mL = Safe; 1-10/100 mL = Intermediate Risk; 11-100/100 mL = High Risk; and >100/100mL = Very High Risk. Water samples were collected and processed by two staff members from WaterAid Cambodia.

Sustainability Scoring

The SWSM is divided into three different levels: domains, sub-domains, and indicators [9] An overall sustainability score for each hospital was generated based on the domain and sub-domain scores derived from the indicator scores. The sustainability score has a range of 0-4 where a higher number indicates greater evidence of an enabling environment for sustainability. Two is the sustainability cut-off point, meaning a score below 2 is not sustainable. The indicator scores were derived from the answers to survey questions, observations, and microbial and chemical water quality tests. Each indicator is associated with answer choices that are valued from 0-4 and are weighted equally to contribute to the sub-domain scores. By averaging the score a hospital received for each indicator within a sub-domain, a sub-domain score was created. These sub-domain scores were then averaged and weighted equally to calculate a domain score. The overall sustainability score gives a snapshot of current conditions at the study hospital, while the sub-domain and indicator scores provide insight on the strengths, weaknesses, opportunities, and threats to the sustainable provision of safe water at that specific hospital.

Quantitative Data Management and Analysis

Results from the surveys and observations were exported into Excel from the mobile platform, and the water quality results were manually entered into an Excel database. Data analyses were performed at Emory University using Microsoft Excel. Analysis involved basic descriptive analyses as described in the sections below.

Total coliforms and E. coli

Water quality results were analyzed to determine the concentration of total coliforms and *E. coli* at each hospital for all time points combined. Box and whisker plots were created in Microsoft Excel for samples with quantifiable levels of *E. coli* and total coliforms in order to examine the distribution and variability.

Water Quality Analysis

Water quality at each hospital was summarized as the percentage of samples that met WHO drinking water quality guidelines [21] (Tables 4-12).

Sustainability Evaluation

Sustainability scores were compared at the domain and sub-domain level within each hospital at three time points (2015/2016, 2017, and 2019). Scores were then further compared between hospitals at 2015/2016, 2017, and 2019.

Qualitative Follow – Up

In-Depth Interviews

Four hospitals were purposively selected for in-depth interviews with the hospital director and maintenance team. (Oudong, Kampong Thom, Thmar Kol, and Sampov Lun). The hospitals with the two highest and two lowest SWSM scores in 2019 were selected in order to have a range of perspectives, and to examine similarities and differences between low vs. high scoring hospitals. Interviews lasted 35 to 45 minutes and explored the participants' knowledge, attitudes, and practices towards the water treatment system, with particular focus on how these shifted over the course of the project period.

An open-ended interview guide was developed with questions primarily based upon the domains of the SWSM tool with the most variability in scores across the project period (on-site capacity and institutional engagement). The interviews were conducted in the Khmer language by a researcher from WaterAid Cambodia. Three out of four interviews were recorded and transcribed verbatim into English by a Cambodian graduate student at Emory University. Detailed field notes were used in lieu of a transcript for the one interviewee who did not give his consent to being recorded.

Qualitative Data Management and Analysis

Data analysis was conducted using a thematic approach that utilized deductive codes. A thematic analysis was used to identify patterns of meaning across both low- and high-scoring hospitals. The transcripts were uploaded into MAXQDA2018 where the analysis was conducted. A codebook was developed and an inter-coder agreement exercise was performed to ensure proper coding. Coding started with open coding, in which segments of data were coded by SWSM domains, or the parent codes. The next step focused on coding with the sub-codes that were the sub-domains of the SWSM tool. Once coding of all four interviews was complete, coded segments on each SWSM domain were retrieved, and distilled into themes, paying closing attention to differences in responses between leadership from low vs. high-scoring hospitals.

Human Subjects and Ethical Considerations

Participation in the interviews and surveys was voluntary and no monetary incentive was offered. Following a brief oral description of the study and research activity, participants provided both their verbal and written consent to participate in the activity. The research plan was reviewed by the Institutional Review Board (IRB) at Emory University and approved as exempt (IRB00078907). Additionally, the protocol was approved by the National Ethics Committee for Health Research in Cambodia (114NECHR and 334NECHR).

Results

An explanatory mixed-methods study was conducted to assess the sustainability of donated water treatment systems in nine hospitals. The SWSM was used to collect quantitative data on four domains of sustainability (Technical Feasibility, On-Site Capacity, Institutional Engagement, and Accountability). Interviews were subsequently conducted with leadership from a subset of hospitals to help explain the quantitative sustainability scores, as well as to uncover additional factors affecting sustainability. Here, we present the quantitative and qualitative findings.

Quantitative Sustainability Evaluation

Nine hospitals were evaluated across three time points, spanning a four-year period from 2015 to 2019. The 2017 data collection period is when donor support ended, and system responsibility was transferred to the hospitals. Two hospitals had data collected at only two time points, Baray Santuk and Bun Rany Hun Sen Hospitals, due to the limited availability of staff to participate in surveys. Each hospital was systematically evaluated, and an overall sustainability score on a scale of 0-4 was calculated (Table 3) with 0 indicating there was no evidence of an enabling environment for sustainability and 4 indicating the maximum evidence of an enabling environment**.** The shaded in boxes in Table 3 represent systems that were not working at the time of the 2019 assessment. The master scoring guide is presented in appendix 1. The full scoring results (overall, domain, and sub-domain scores) for all hospitals are presented in appendix 2. The overall scores (Figures 4-6), as well as domain score comparisons for the four case study hospitals (Figures 7-10) are displayed on radar plots for 2015/2016, 2017, and 2019. Domain score comparisons for the other five hospitals are displayed in Appendix 3, and the sub-domain scores for all hospitals are presented on radar plots in Appendix 4.

Table 3: Overall Sustainability Scores by Year for each Hospital

Year	B Santuk	Kg Thom	Kg Trach	Kg Tralach	Koh Thom	Oudongk	Sampov Lun	Thmar Kol	Bun Rany
2016	2.3	2.2	2.5	2.5	2.2	2.5	2.4	2.4	2.0
2017	2.8	2.5	2.9	2.7	3.0	2.9	2.7	2.6	X
2019*	X	3.0**	3.2	3.3	3.3^	2.7	3.1	3.4	2.4+

X – no data collected
* - All 2019 scores are missing the sub-domain Plumbing Infrastructure, within Technical Feasibility Domain.
**- Missing External oversight and Budgeting sub-domains within Accountability domain, and Ownership sub-domain within Institutional Engagement Domain
^ - Missing Water Quality sub-domain within Technical Feasibility
\+ - Missing Water Quality sub-domain within Technical Feasibility, Operation and Training sub-domains within On-Site Capacity
Shaded boxes indicate hospitals where the water treatment system was not functioning or was no longer in use at the time of the 2019 assessment.

Overall Sustainability Scores

All nine hospitals showed an increase in their overall sustainability score over the four-year project period (Table 3, Figure 3). The scores consistently increased over time in all hospitals except Oudongk, which had a decrease in its overall score from 2017 to 2019. In 2016, the average sustainability score for all nine hospitals was 2.3 with a range of 2.0 to 2.5. In 2017, the average sustainability score was 2.7 with a range of 2.5 to 3.0. In 2019, the average sustainability score for the eight hospitals that were assessed was 3.0 with a range of 2.4 to 3.3. Overall, the average increase in sustainability score per hospital was 0.69 points over the four-year time period with the smallest increase of 0.2 points (Oudongk) and the largest increase of 1.1 points (Koh Thom). A score of 2.0 is the cut-off for sustainability, or when there starts to be some evidence of an enabling environment for sustainability. At the initial assessment in 2015, all hospitals had scores at, or slightly above, this cut-off point, and as the project progressed, all hospitals increased their scores in the direction of higher sustainability.

Figure 3: Overall Sustainability Scores for the Nine Hospitals Across Three Assessment Periods

Domain Specific Results

While each hospital demonstrated improvement in at least one domain, many domain scores decreased between years or were close to the sustainability cut-off score of 2.0. On-Site Capacity was commonly one of the lowest scoring domains across hospitals and evaluation years. Domain-specific results are presented below.

Technical Feasibility

Technical Feasibility consistently had the highest average domain score across all evaluation years. In 2016, the average score was 2.3 with a range of 2.1 – 3.1. In 2017, the average score was 2.7 with a range of 3.0 to 3.6, and in 2019, the average score was 3.0 with a range of 2.3 to 4.0. Water quantity and availability had the highest average sub-domain score across all evaluation years with all hospitals attaining the maximum score of 4 in 2017, but then declining to 3.6 in 2019. The average water quality sub-domain score increased from 2.7 in 2016 to 3.3 in 2017 but then decreased in 2019 with an average score of 2.7. Kampong Thom, Kampong Trach, and Kampong Tralach all received a score of 4.0 in 2019 for the water quality sub-domain, while Sampov Lun and Oudongk, which were hospitals with non-functional systems at the time of the 2019 assessment, received a score of 1 and 0 respectively. Plumbing infrastructure was consistently the lowest scoring sub-domain across all evaluation years, although plumbing infrastructure was not observed during the 2019 assessment. In 2016, the average score for plumbing infrastructure was 2.4 with only three hospitals receiving a score of 4.0.

On-Site Capacity

On-site capacity was consistently a low-scoring domain across all hospitals and evaluation years. In 2016, the average domain score was 2.3 with a range of 1.8 to 2.8. In 2017, the average domain score was 2.4 with a range of 1.9 to 2.8. In 2019, the average domain score decreased to 2.1 with a range of 1.6 to 2.8. A domain score of 2.8 was the highest score achieved by any hospital throughout the project period, which is just above the sustainability cut-off point of 2.0. These low scores are most notably from the preventative maintenance and repair sub-domain which had average scores below the sustainability cut-off at every evaluation year. Additionally, the low average domain score in 2019 can be attributed to the decrease in the sub-domains for operation and training.

Financial & Operational Accountability

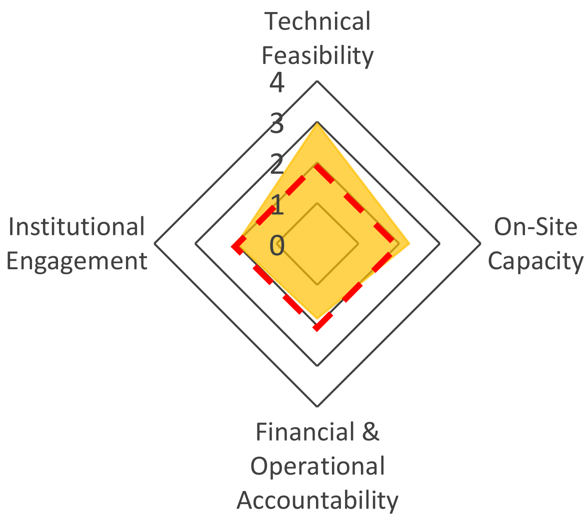
The accountability domain had the lowest average scores (2.0) during the 2016 and 2017 assessments, and then transitioned to the highest scoring domain in 2019 (alongside technical feasibility) with an average score of 3.5. The low scores within this domain in 2016 and 2017 can be attributed to all hospitals receiving a score of 0 for the sub-domain external oversight. Moving into 2019, seven out of the eight hospitals assessed scored a 4.0 within this domain, thus explaining the overall domain score increase. The internal oversight sub-domain scores decreased from 2016 to 2017 which may have been a result of treatment system responsibility transitioning to the hospitals in 2017. This sub-domain average score increased by one point from 2017 to 2019 which signifies that the hospitals were becoming more comfortable and familiar with the systems. The sub-domain scores for budgeting consistently increased for all hospitals at each evaluation year, ending with a score of 4.0 for all in 2019.

Institutional Engagement

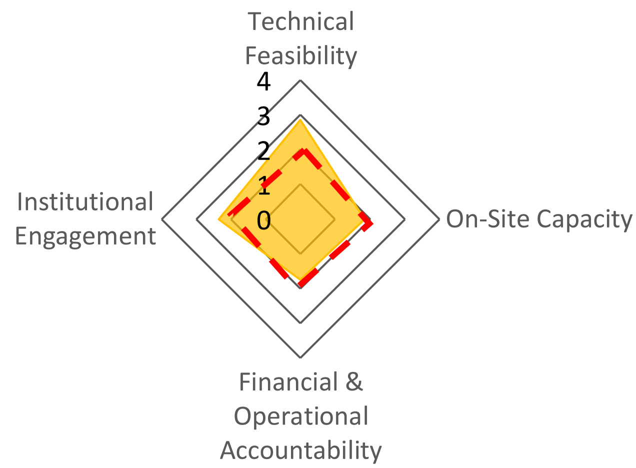
The domain for institutional engagement had an average overall score in 2016 of 2.3 with a range of 1.9 to 2.7. In 2017, the average score increased to 3.2 with a range of 3.0 to 3.5. The average score then decreased in 2019 to 3.0 with a range of 2.4 to 3.5. The sub-domain for staff awareness and support started with an average score of 2.0, increasing to 2.6 in 2017, and then decreasing in 2019 to 2.0. Additionally, the sub-domain for staff participation and use of treated water was a consistently low scoring sub-domain with no change in the average scores from 2017 to 2019. Lastly, the sub-domain for ownership saw a decrease in average score of 4.0 in 2017 to an average score of 3.3 in 2019.

Figure 4. 2015/2016 Domain Specific Sustainability Scores by Hospital

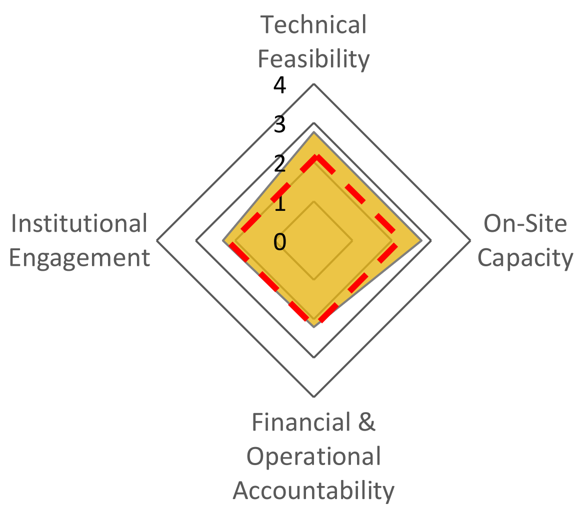
A. Baray Santuk



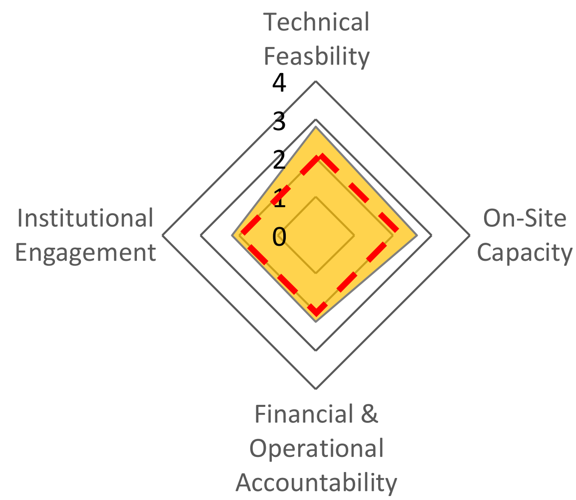
B. Kampong Thom



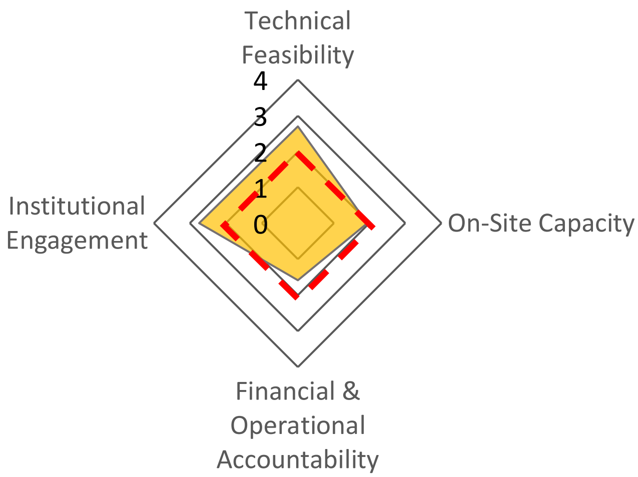
C. Kampong Trach



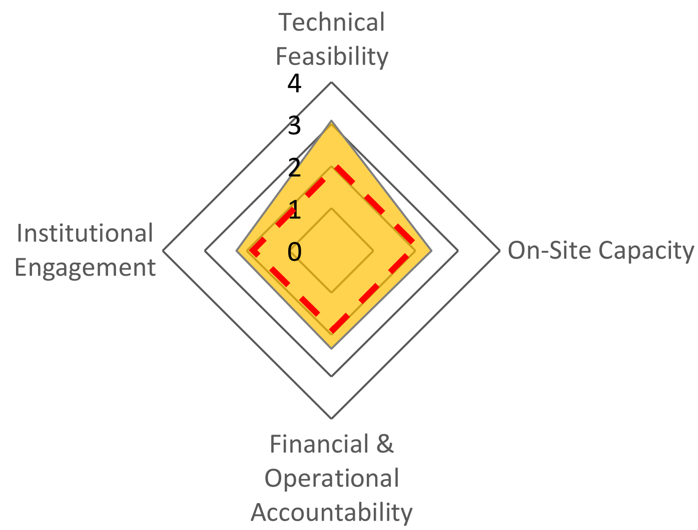
D. Kampong Tralach



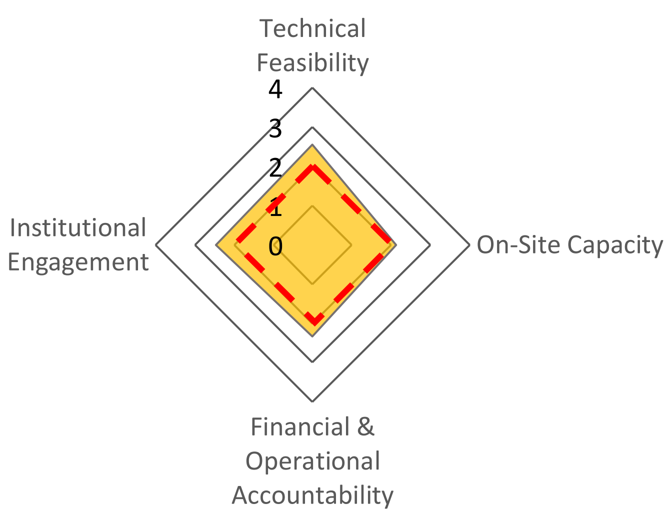
E. Koh Thom



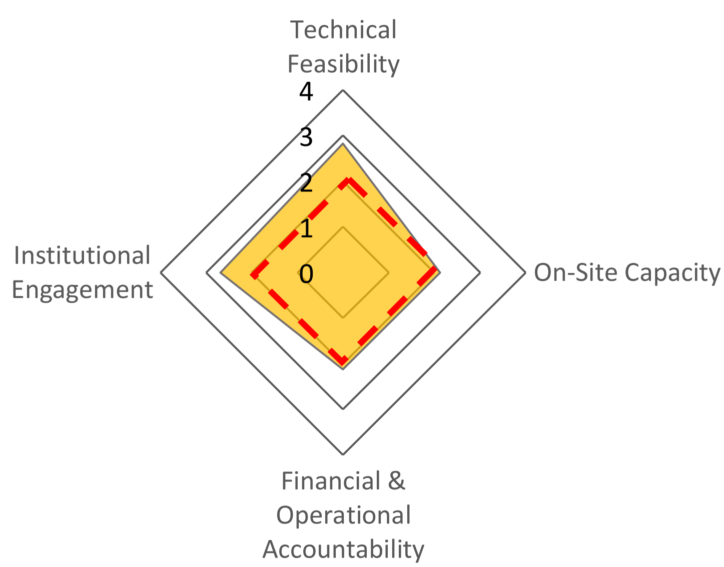
F. Oudongk



G. Sampov Lun



H. Thmar Kol



I. Bun Rany Hun Sen

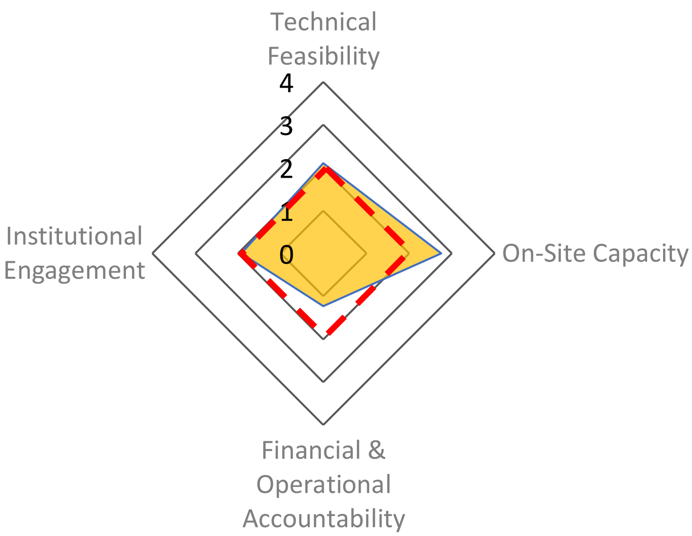
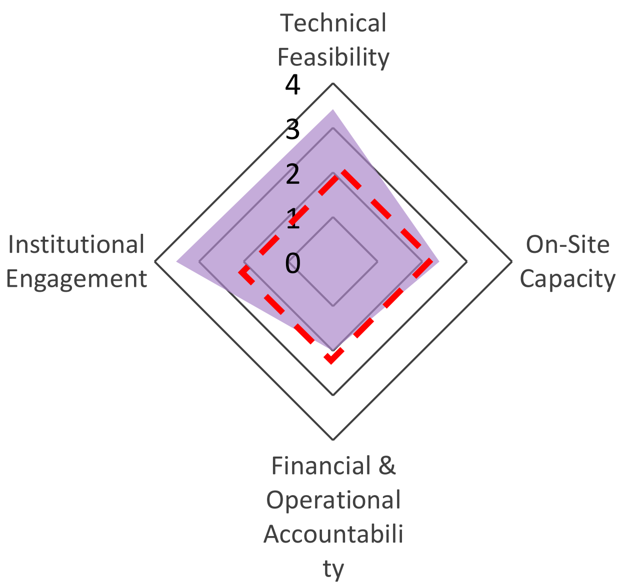
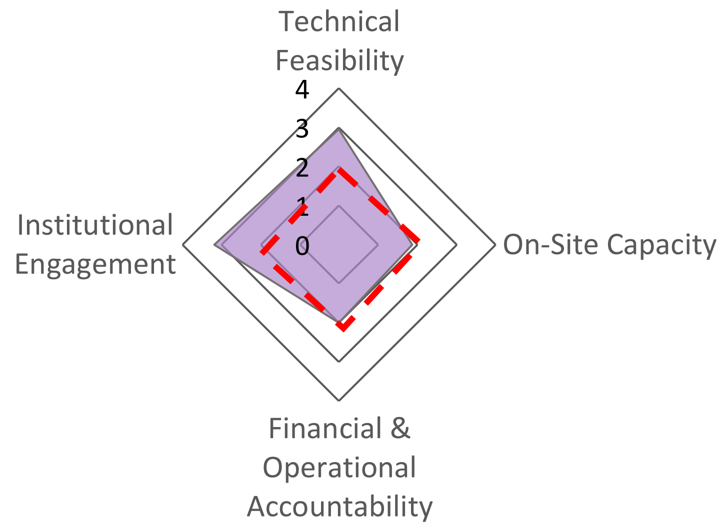


Figure 5. 2017 Domain Specific Sustainability Scores by Hospital

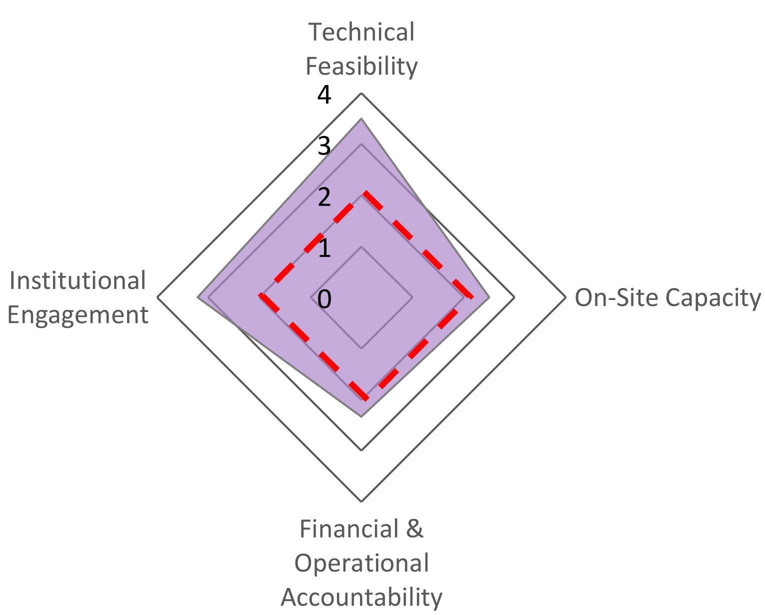
A. Baray Santuk



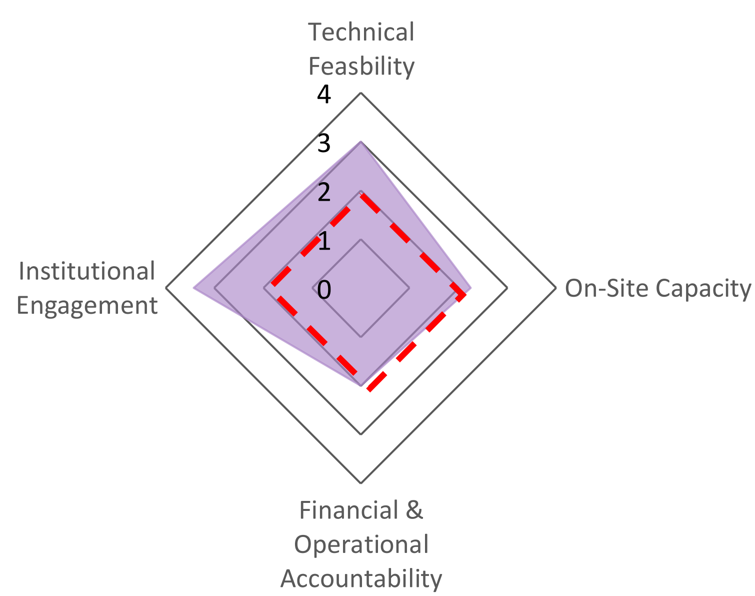
B. Kampong Thom



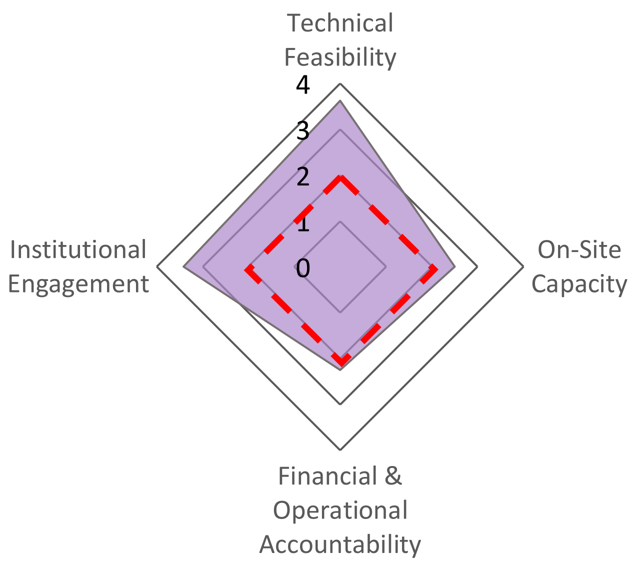
C. Kampong Trach



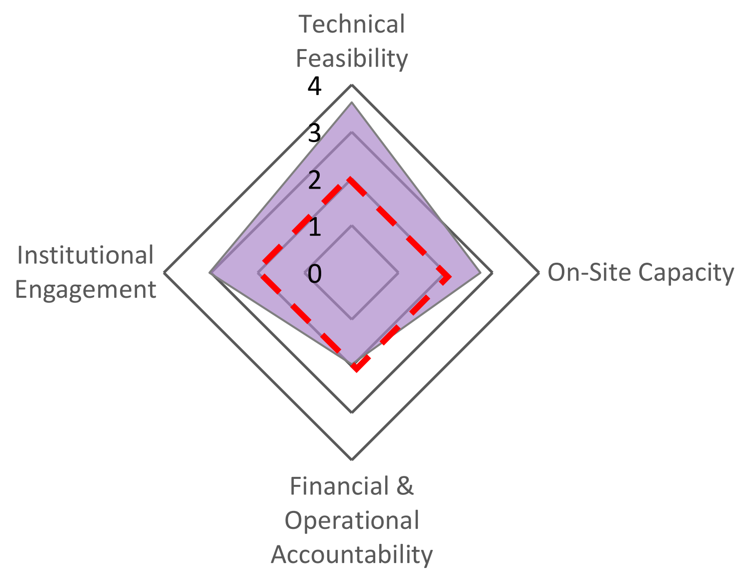
D. Kampong Tralach



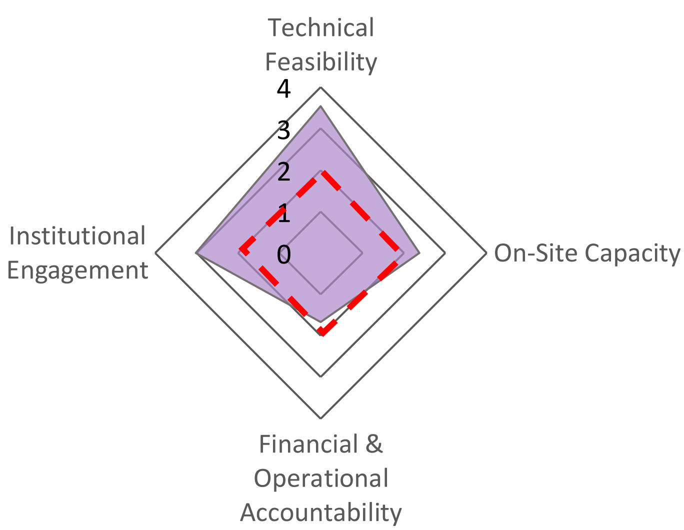
E. Koh Thom



F. Oudongk



G. Sampov Lun



H. Thmar Kol

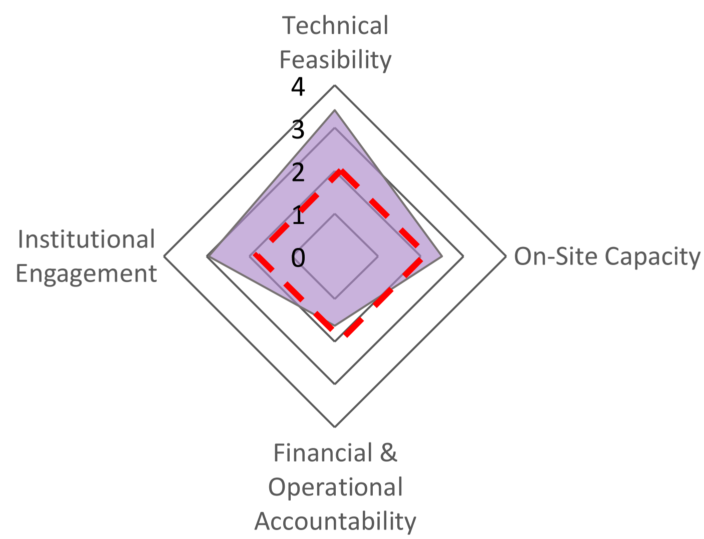
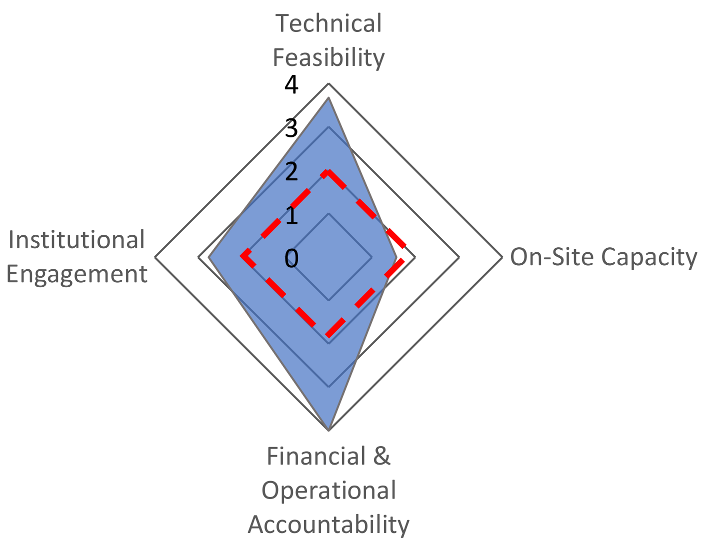
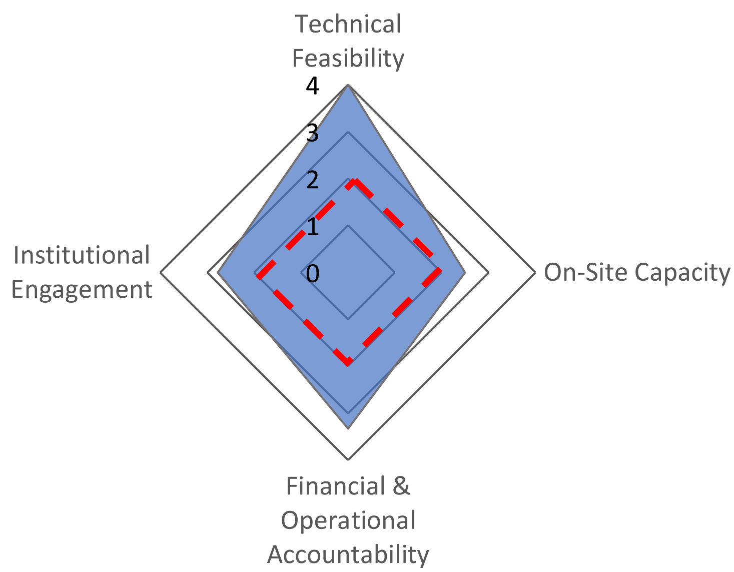


Figure 6. 2019 Domain Specific Sustainability Scores by Hospital

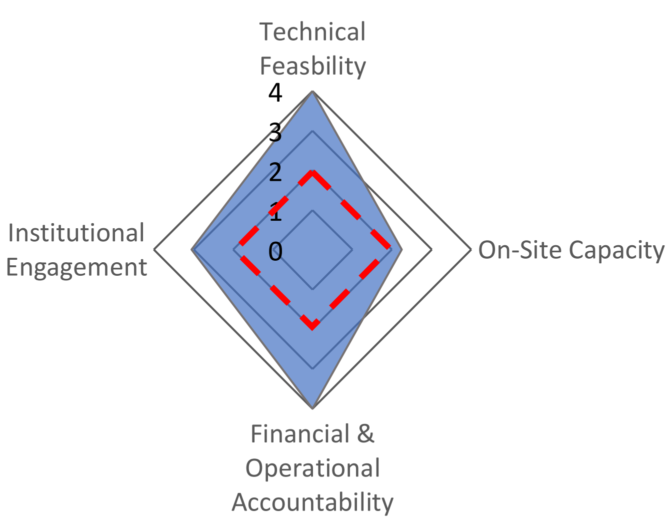
A. Kampong Thom



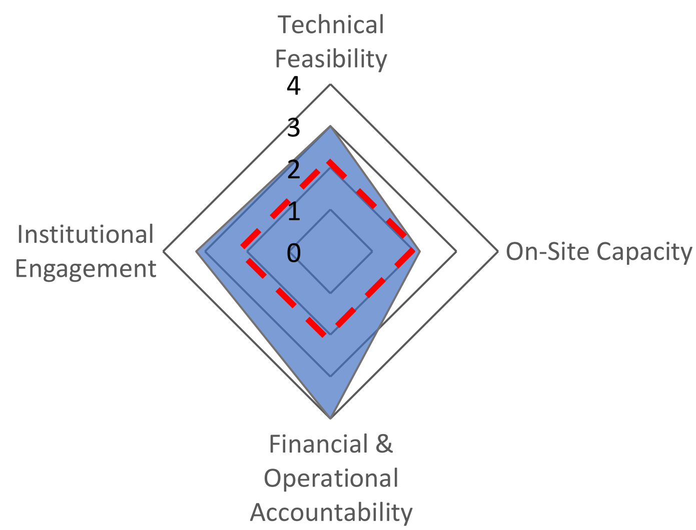
B. Kampong Trach



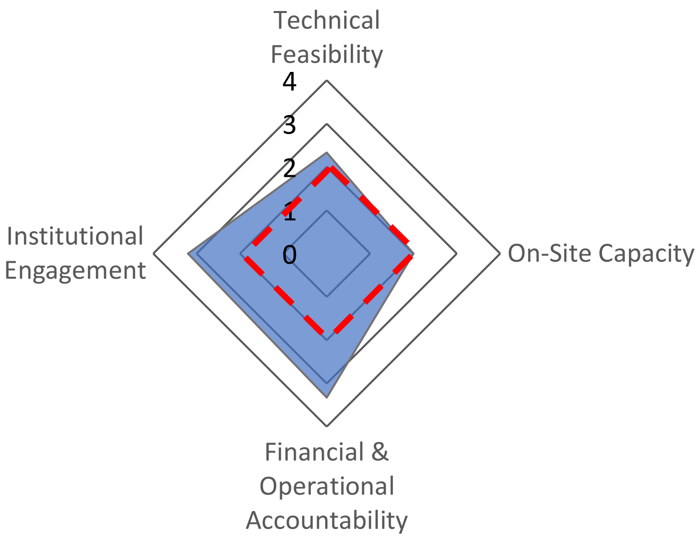
C. Kampong Tralach



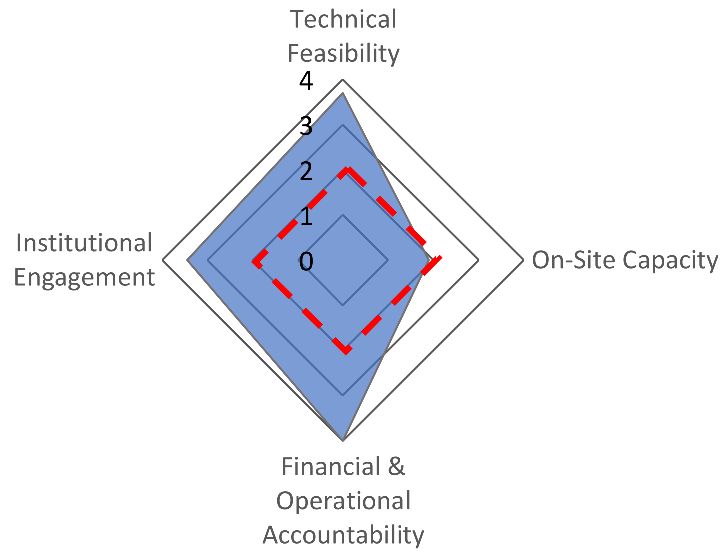
D. Koh Thom



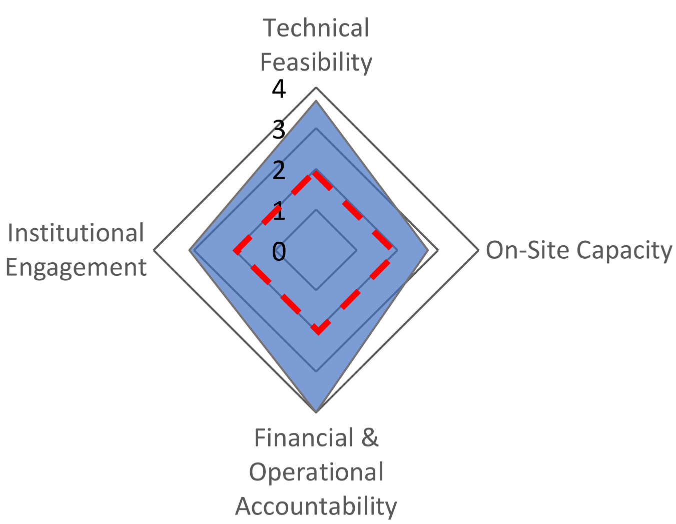
E. Oudongk



F. Sampov Lun



G. Thmar Kol



H. Bun Rany Hun Sen

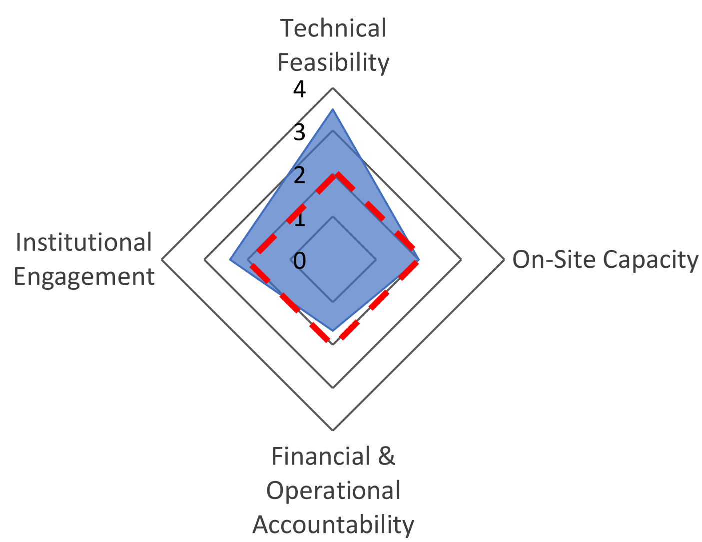


Figure 7. Kampong Thom Hospital – Sustainability Domain Scores 2015/6 vs. 2017 vs. 2019

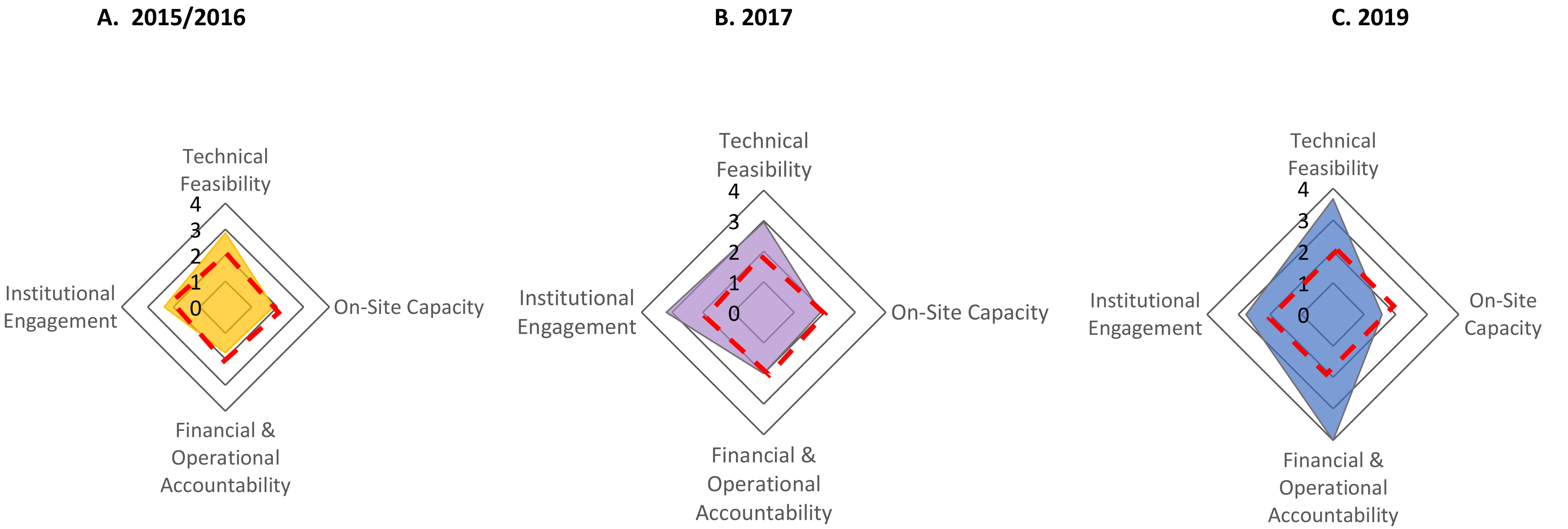
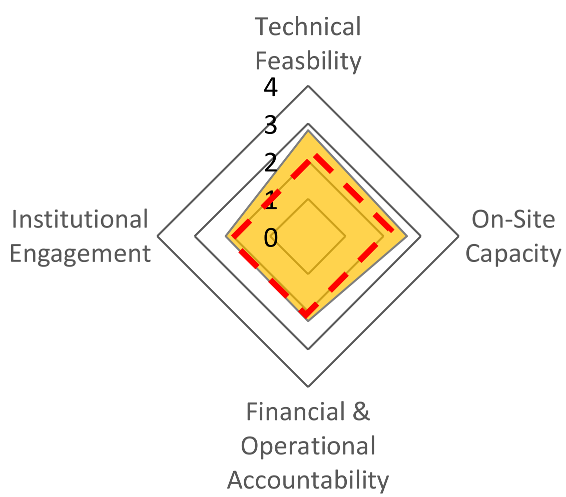
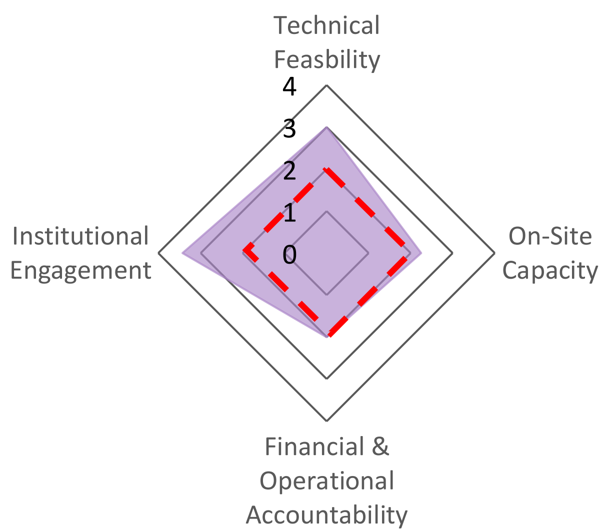


Figure 8. Kampong Tralach Hospital – Sustainability Domain Scores 2015/6 vs. 2017 vs. 2019

A. 2015/2016



B. 2017



C. 2019

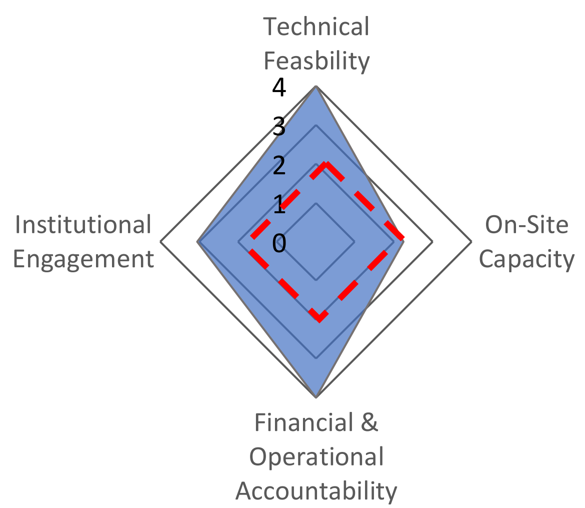
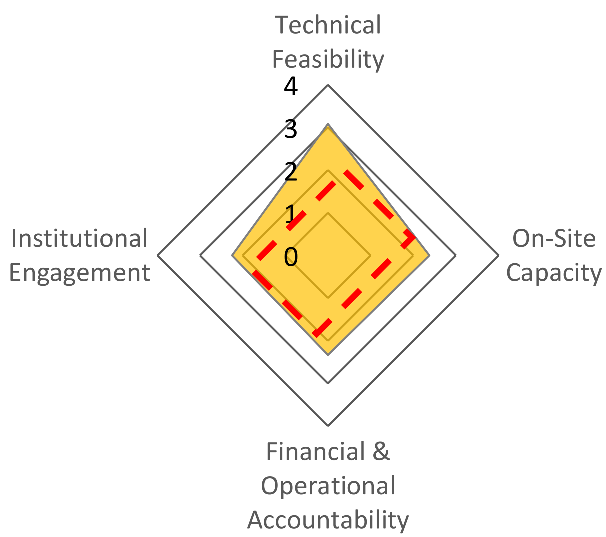
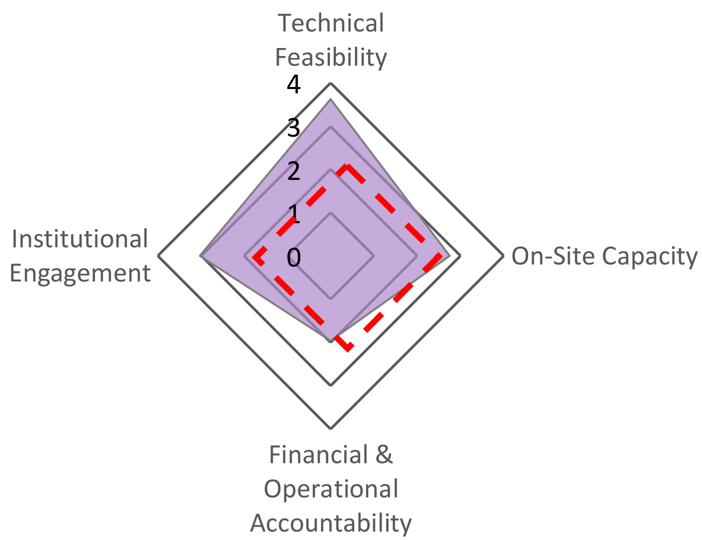


Figure 9. Oudongk Hospital – Sustainability Domain Scores 2015/2016 vs. 2017 vs. 2019

A. 2015/2016



B. 2017



C. 2019

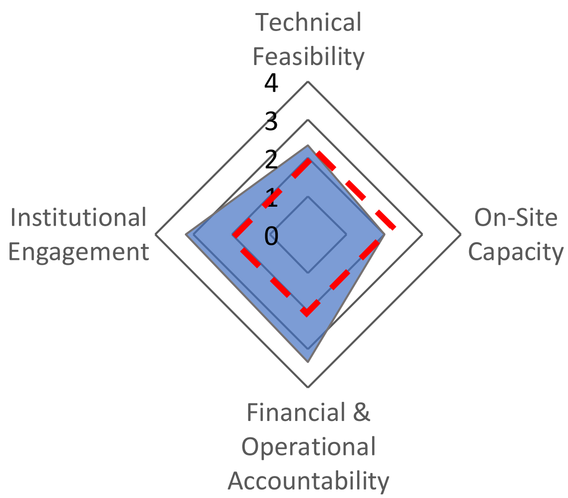
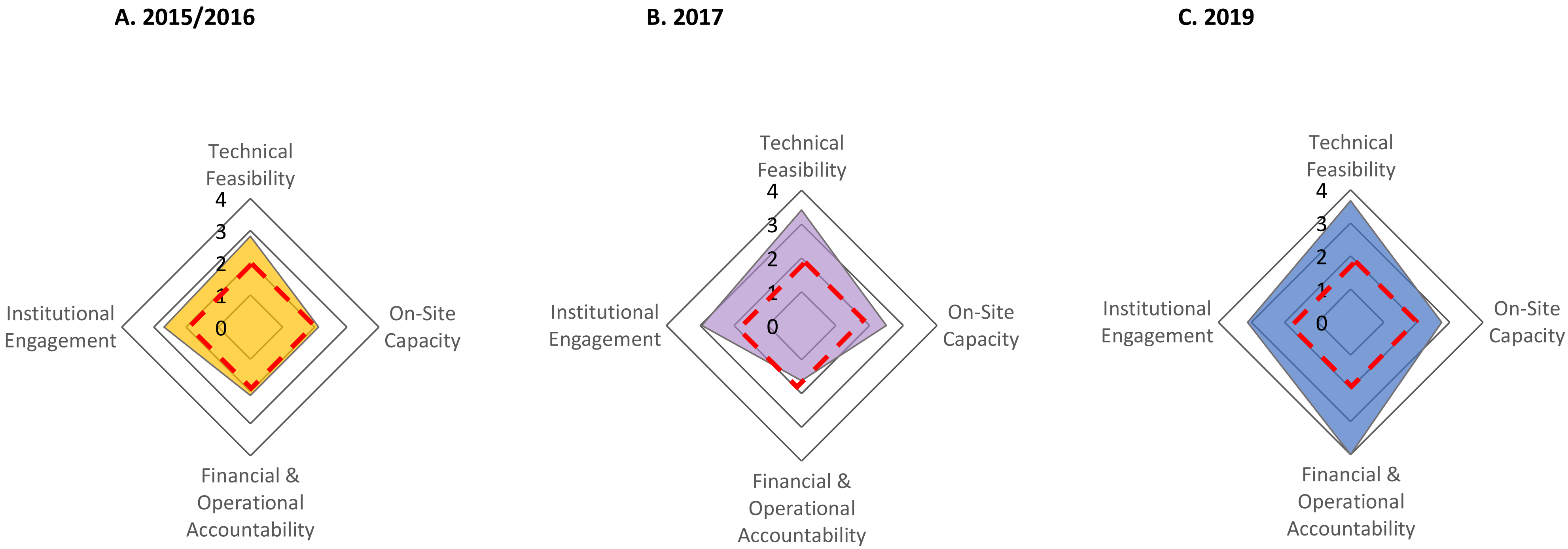


Figure 10. Thmar Kol Hospital – Sustainability Domain Scores 2015/2016 vs. 2017 vs. 2019



Water Quality

The total number of water samples collected from each hospital per year were aggregated. The percentage of samples that met WHO guidelines for drinking water quality [21] for total coliforms (acceptable range: <1 MPN / 100mL), *E. coli* (acceptable range: <1 MPN / 100mL), Turbidity (acceptable range: <5 NTU / 100), free chlorine residual (acceptable range: 0.2 – 2.0 mg/L), and total chlorine (acceptable range: > 0.2 mg/L) were calculated by hospital (Tables 4-10**).** Sampov Lun had the least number of samples tested because the treatment system was bypassed from May 2016 – August 2016. . Seven out of nine hospitals had 100% of samples test within the range for turbidity, except for Kampong Thom and Oudongk who were in the 98% range.

The samples that had detectable total coliforms in 100mL were aggregated per hospital. The concentrations of the samples are presented in box and whisker plots for each hospital (Figure 12). For all hospital sites, the majority of samples had <1 MPN / 100mL for total coliforms and *E. coli*. All hospitals had some samples (7%-28%) with concentrations >1 MPN / 100mL for total coliforms. Oudongk had the highest mean concentration for total coliforms at 40 MPN/100mL (Figure 12), followed by Baray Santuk and Kampong Thom. Sampov Lun had the lowest mean concentration for total coliforms at 1.5 MPN/ 100ml (Figure 12). E. *coli* was detected in six hospitals. The total number of positive samples per hospital ranged from 2 to 13. The mean concentration was 6.2MPN/100mL, and the range was a minimum of 1 MPN/100mL to a maximum of 48.3 MPN/100mL

Free chlorine residual levels were aggregated for all samples per hospital and presented in Figure 11. Five out of nine hospitals had the majority of samples (70-100%) test within the recommend range for free chlorine residual. Kampong Thom, Kampong Trach, Oudongk, and

Thmar Kol had 40% or less of samples test within the range for free chlorine residual. Kampong Thom, Kampong Trach, and Oudongk also tested low for total chlorine, with only 40-60% of samples testing within the range. The other six hospitals had the majority of samples (70-100%) test within range for total chlorine.

Figure 11. Free Chlorine Concentration for all Samples per Hospital

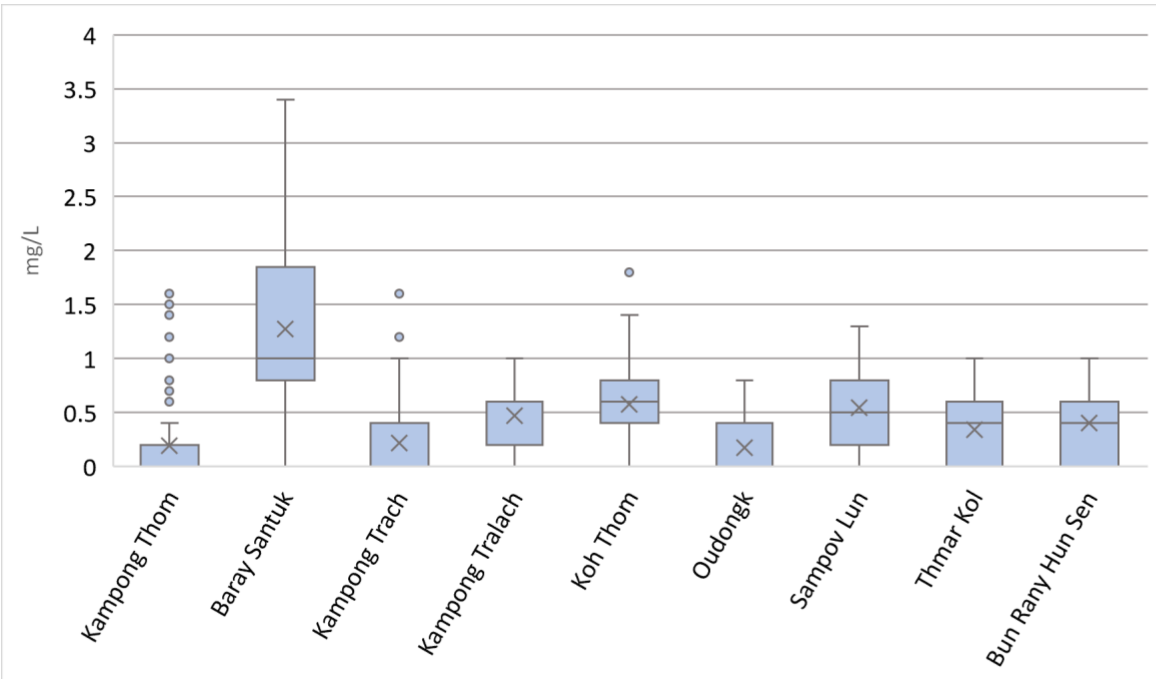


Table 4. Percentage of Samples per Year that Met WHO Guidelines for Drinking Water Quality [21] - Baray Santuk Hospital

Year (N)	Total Coliforms % of Samples	*E. coli* % of Samples	Free Chlorine % of Samples	Total Chlorine** % of Samples	Turbidity % of Samples
2015 (46)	**93.5**	**100**	**65.2**	**82.6**	**100**
2016 (73)	**87.7**	**100**	**84.9**	**93.2**	**100**
2017 (5)	**100**	**100**	**100**	**X**	**100**
2019 (8)	**X**	**25**	**X**	**X**	**X**
Total	**90.3**	**95.5**	**78.2**	**95.5**	**100**

**E.coli* results include more samples due to the Aquagenx testing done in 2019
** Total chlorine was not measured in 2017
*** Did not collect 2017 water quality data
X – missing data

Table 5. Percentage of Samples per Year that Met WHO Guidelines for Drinking Water Quality [21] - Kampong Thom Hospital

Year (n)	Total Coliforms % of Samples	E. *coli*^ % of Samples	Free Chlorine % of Samples	Total Chlorine** % of Samples	Turbidity % of Samples
2015 (48)	**79.2**	**100**	**37.5**	**66.7**	**95.8**
2016 (74)	**78.4**	**97.3**	**28.4**	**62.2**	**100**
2017 (5)	**20**	**100**	**0**	**X**	**100**
2019 (6)	**X**	**100**	**X**	**X**	**X**
Total	**76.4**	**98.5**	**30.7**	**63.9**	**98.4**

*E.coli results include more samples due to the Aquagenx testing done in 2019
** Total chlorine was not measured in 2017
*** Did not collect 2017 water quality data
X – missing data
^ - 2 E.coli Samples both had concentration of 1 MPN/100mL

Table 6. Percentage of Samples per Year that Met WHO Guidelines for Drinking Water Quality [21] - Kampong Trach Hospital

Year (n)	Total Coliforms % of Samples	E. *coli** % of Samples	Free Chlorine % of Samples	Total Chlorine** % of Samples	Turbidity % of Samples
2015 (6)	**100**	**100**	**0**	**0**	**100**
2016 (78)	**76.9**	**94.9**	**34.6**	**44.9**	**100**
2017 (5)	**100**	**100**	**100**	**X**	**100**
2019 (5)	**X**	**100**	**X**	**X**	**X**
Total	**79.8**	**95.7**	**36.0**	**41.7**	**100**

*E.coli results include more samples due to the Aquagenx testing done in 2019
** Total chlorine was not measured in 2017
*** Did not collect 2017 water quality data
X – missing data

Table 7. Percentage of Samples per Year that Met WHO Guidelines for Drinking Water Quality [21] - Kampong Tralach Hospital

Year (n)	Total Coliforms % of Samples	E. *coli** % of Samples	Free Chlorine % of Samples	Total Chlorine** % of Samples	Turbidity % of Samples
2015 (4)	**50**	**100**	**0**	**25**	**100**
2016 (64)	**81.3**	**100**	**92.2**	**92.2**	**100**
2017 (5)	**100**	**100**	**0**	**X**	**100**
2019 (5)	**X**	**100**	**X**	**X**	**X**
Total	**80.8**	**100**	**80.8**	**88.2**	**100**

*E.coli results include more samples due to the Aquagenx testing done in 2019
** Total chlorine was not measured in 2017
*** Did not collect 2017 water quality data
X – missing data

Table 8. Percentage of Samples per Year that Met WHO Guidelines for Drinking Water Quality [21] - Koh Thom Hospital

Year (n)	Total Coliforms % of Samples	E. *coli** % of Samples	Free Chlorine % of Samples	Total Chlorine** % of Samples	Turbidity % of Samples
2015 (49)	**91.8**	**100**	**69.4**	**81.6**	**100**
2016 (71)	**90.1**	**100**	**94.4**	**98.6**	**100**
2017 (6)	**100**	**100**	**100**	**X**	**100**
2019 (5)	**X**	**100**	**X**	**X**	**X**
Total	**91.3**	**100**	**84.9**	**91.7**	**100**

*E.coli results include more samples due to the Aquagenx testing done in 2019
** Total chlorine was not measured in 2017
*** Did not collect 2017 water quality data
X – missing data

Table 9. Percentage of Samples per Year that Met WHO Guidelines for Drinking Water Quality [21] - Oudongk

Year (n)	Total Coliforms % of Samples	E. *coli** % of Samples	Free Chlorine % of Samples	Total Chlorine** % of Samples	Turbidity % of Samples
2015 (8)	**100**	**100**	**0**	**0**	**100**
2016 (83)	**67.5**	**89.2**	**44.6**	**51.8**	**98.8**
2017 (5)	**100**	**100**	**100**	**X**	**100**
2019 (8)	**X**	**20**	**X**	**X**	**X**
Total	**71.9**	**87.1**	**43.8**	**50.0**	**98.9**

*E.coli results include more samples due to the Aquagenx testing done in 2019
** Total chlorine was not measured in 2017
*** Did not collect 2017 water quality data
X – missing data

Table 10. Percentage of Samples per Year that Met WHO Guidelines for Drinking Water Quality [21] - Sampov Lun Hospital

Year (n)	Total Coliforms % of Samples	E. *coli** % of Samples	Free Chlorine % of Samples	Total Chlorine** % of Samples	Turbidity % of Samples
2015 (8)	**100**	**100**	**87.5**	**100**	**100**
2016 (54)	**88.9**	**100**	**92.6**	**96.3**	**100**
2017 (6)	**83.3**	**100**	**100**	**X**	**100**
2019 (5)	**X**	**40**	**X**	**X**	**X**
Total	**89.7**	**95.9**	**92.6**	**95.9**	**100**

*E.coli results include more samples due to the Aquagenx testing done in 2019
** Total chlorine was not measured in 2017
*** Did not collect 2017 water quality data
X – missing data

Table 11. Percentage of Samples per Year that Met WHO Guidelines for Drinking Water Quality [21] - Thmar Kol Hospital

Year (n)	Total Coliforms % of Samples	E. *coli** % of Samples	Free Chlorine % of Samples	Total Chlorine** % of Samples	Turbidity % of Samples
2015 (8)	**100**	**100**	**75.0**	**100**	**100**
2016 (75)	**90.7**	**100**	**73.3**	**68.0**	**100**
2017 (5)	**100**	**100**	**0**	**X**	**100**
2019 (5)	**X**	**100**	**X**	**X**	**X**
Total	**92.0**	**100**	**69.3**	**71.1**	**100**

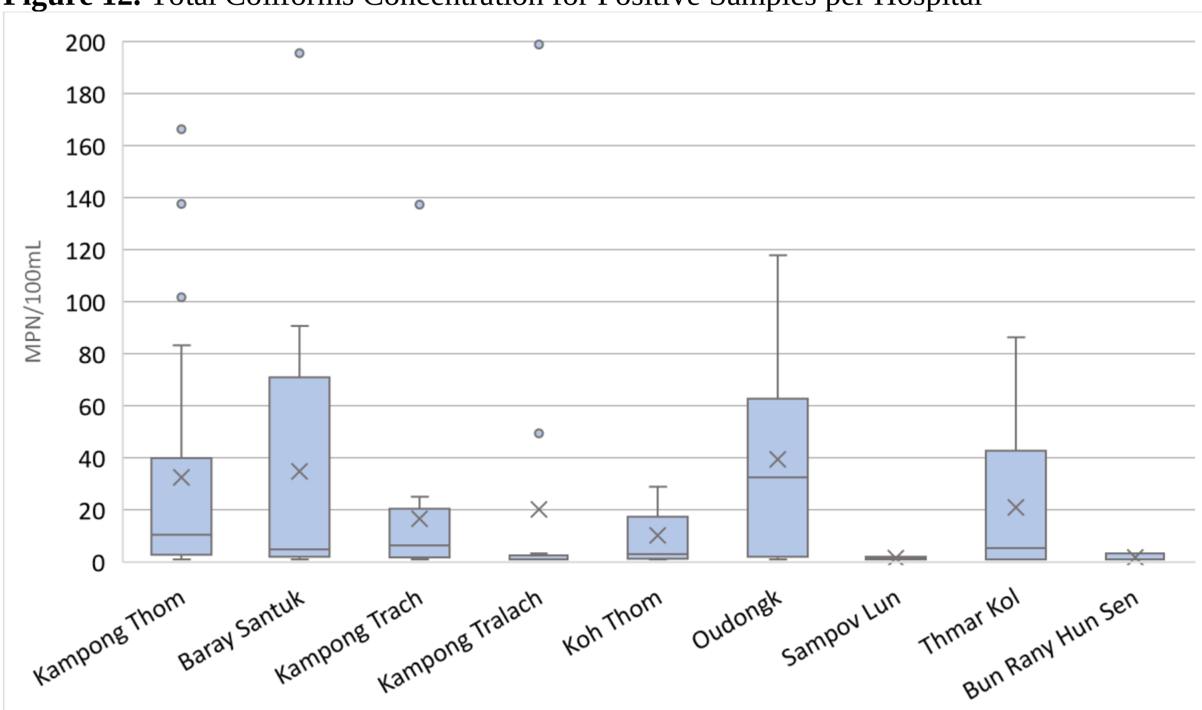
*E.coli results include more samples due to the Aquagenx testing done in 2019
** Total chlorine was not measured in 2017
*** Did not collect 2017 water quality data
X – missing data

Table 12. Percentage of Samples per Year that Met WHO Guidelines for Drinking Water Quality [21] - Bun Rany Hun Sen Hospital***

Year (n)	Total Coliforms % of Samples	E. *coli** % of Samples	Free Chlorine % of Samples	Total Chlorine** % of Samples	Turbidity % of Samples
2015 (6)	**83.3**	**100**	**0**	**0**	**100**
2016 (81)	**92.6**	**98.8**	**75.3**	**84.0**	**100**
2019 (5)	**X**	**80**	**X**	**X**	**X**
Total	**91.9**	**97.8**	**70.1**	**78.2**	**100**

*E.coli results include more samples due to the Aquagenx testing done in 2019
** Total chlorine was not measured in 2017
*** Did not collect 2017 water quality data
X – missing data

Figure 12. Total Coliforms Concentration for Positive Samples per Hospital



Qualitative Follow-up of Four Case Study Hospitals

Four hospitals were purposively sampled for the qualitative follow–up study. The selected hospitals included the two with the lowest overall sustainability score in 2019 (Kampong Thom and Oudongk Hospitals) and the two with the highest overall scores in 2019 (Kampong Tralach and Thmar Kol Hospitals). All four hospitals are in urban areas, but the size of the hospitals varies. Kampong Tralach and Oudongk are the smallest hospitals, seeing on average 40 outpatients per month. Thmar Kol and Kampong Thom hospitals are the largest, seeing on average 812 outpatients per month. Lastly, Thmar Kol and Kampong Thom are hospitals located in northern provinces away from the capital city, while Oudongk and Kampong Tralach hospitals are in southern provinces closer to the capital city. The respective hospital director participated in the interview at Kampong Tralach, Thmar Kol, and Oudongk hospitals, while both the hospital director and the maintenance worker at Kampong Thom Hospital were interviewed.

Each of the four sustainability domains from the SWSM were explored in the interviews, and as such we present the thematic findings by domain, noting similarities and differences between the low- and high-scoring hospitals. The following key questions were considered when analyzing the themes for each domain: Technical Feasibility – are the water treatment systems working?; Accountability – can the hospitals afford the water treatment systems?; Capacity – can the hospitals maintain and operate the water treatment systems?; Engagement – are the hospitals satisfied with the water treatment system?

Technical Feasibility

For sustained access to safe water, it is important for the technology to be reliable and appropriate for the HCF's water and power sources. Additionally, supplies for water treatment and system repair should be available locally. As such, for technical feasibility we examined the hospitals' overall water infrastructure, their access to supplies and equipment, and system functionality.

All hospitals had adequate water infrastructure for their water treatment system, but the low-scoring hospitals described frequent water shortages and subsequent reliance on a backup source. All four hospitals were connected to the public water authority and had a backup water source - Kampong Thom and Thmar Kol hospitals used a water reservoir, while Oudongk and Kampong Tralach hospitals used wells. All hospitals had automatic connection to their backup source in the case of shortage from the public water authority, except for Kampong Tralach which had to manually switch to the well. Both high- scoring hospitals did not experience any water shortages in 2019, while both low-scoring hospitals experienced frequent shortages. When a water shortage occurred, the hospital simply switched to the backup source.

> *"Last time we had a water shortage was last week. It used to happen many times due to issues at the government water supply authority. Sometimes we did not know that the water was cut off because normally the water runs through reservoir to keep it full, and when the water was cut off then it will automatically switch to the reservoir."*
>
> *-Hospital Director, Kampong Thom Hospital*

While all hospitals stated it was not difficult to find simple spare parts like small tubes, wires, and taps, the water treatment systems in the low-scoring hospitals that were not working was due to the lack of more complex replacement parts. The main water switch for the Kampong Thom system was broken, while the main pipes for the system at Oudongk were broken. It was noted by both of these hospitals that it was hard to find these replacement parts because they are more complex parts. Both directors stated that since their water treatment system was down and they could not find the spare part, they had locked up the system in storage.

"The system has ended up being put on hold and the facility is locked in storage. The system has serious problem that cannot be fixed."

-Hospital Director, Kampong Thom Hospital

However, at both high-scoring hospitals the water treatment systems were working, and neither hospital had experienced any major breakdown.

Financial and Operational Accountability

WASH in HCFs is usually a low priority for ministries of health, and the responsibility is often spread across multiple governing bodies. This in turn creates a lack of clarity over who is responsible for improvements and who should pay [40]. For this domain, we examined the hospital's ability to fund the system, the effects of any third-party support, and system monitoring mechanisms.

All hospital directors reported that they could fund their water treatment system, but they did so using different approaches and to varying degrees. Securing money for small repairs was not difficult for the case study hospitals. However, the amount that was considered small varied with some hospitals able to afford repairs up to $200 and others up to $500. Additionally, the high-scoring hospitals used hospital finances procured from patient fees to subsidize the water treatment system, while the low-scoring hospitals utilized both hospital and government funding streams.

Hospitals could afford small repairs, but when it came to larger expenses like staff, there were clear differences. Both high-scoring hospitals could afford to hire additional staff members to monitor the system while low-scoring hospitals could not. The director at Kampong Thom hospital mentioned that a barrier to operating and maintaining the water system was not having the funds available to hire a daily maintenance worker.

All of the hospitals received support from a third-party, primarily for repairs but in some cases also for spare parts. Three out of the four hospitals mentioned needing to utilize the technical partner Assist International (AI) from the project contract to help repair the water treatment system. When Thmar Kol and Oudongk contacted AI for assistance, their problem was fixed within a day. Kampong Thom was not been able to get a worker to visit the hospital to fix the water treatment system, despite the director being highly motivated to address the problem. In addition to AI, Kampong Tralach had an additional partnership outside of the project contract where they were provided taps and water filters on an as-needed basis.

Three out of the four hospitals explained how they monitored their water treatment system. All three of these hospitals had at least one contracted out staff member responsible for monitoring, although the contract worker at Oudongk did not know the maintenance logs existed. Two hospitals mentioned delegating tasks to two hospital staff members in addition to the contract worker, but these staff members did not have set schedules to monitor the system due to their demanding work schedules.

On-Site Capacity

The capacity of both maintenance staff and leadership to be able to maintain the water treatment system over time is crucial for sustained, safe water access in a HCF. As such, for this domain we examined capacity for communication among patients, staff, and leadership, as well as training around the system, and system repairs.

Communication about repairs between maintenance personnel and directors varied by hospital. Some hospitals had an organized chain of communication for relaying repair needs of the water treatment system, while one hospital gave the authority for repairs to its maintenance personnel, requiring no communication structure. At Kampong Tralach, the maintenance staff reported to the accountant when a repair was needed, and then together they reported this to the director. Kampong Thom Hospital's maintenance personnel reported to the director who then reported to the accountant to make the final decision. Lastly, at Oudongk Hospital, the director did not engage with maintenance personnel often, and this staff member had the authority to conduct repairs without his permission. In this situation, the director seemed least engaged, so this communication system seemed to not work. Thmar Kol Hospital director did not discuss their chain of communication during the interview.

The way in which hospital leadership communicated with both patients and staff about the water system also varied by hospital. Regarding hospital leadership communicating with staff about the water treatment system, Oudongk's director said there were no clear roles, but that he informally talked with the staff about the water.

> *"The staff does not need to understand the maintenance of the treatment system; they just need to know that we have a clean water system."*
>
> *-Hospital Director, Oudongk Hospital*

At Kampong Tralach hospital, the director discussed the system with the staff at every monthly staff meeting, and the staff also communicated with the patients about the clean water. At Kampong Thom hospital, the director advised the patients to not drink the water since the system was down. The Thmar Kol Hospital director did not discuss how leadership communicated with staff and patients during the interview.

Both high-scoring hospitals had at least one staff member who was trained by AI and was still working at the hospital, and these staff members were able to maintain and operate the system. In contrast, both low-scoring hospitals no longer had a staff member who was trained by AI working at the hospital, and there had been no trainings for new staff since the start of the program.

> *"The previous staff responsible for taking care of the facility also retired, so it is not operating anymore."*
>
> *-Hospital Director, Kampong Thom Hospital*

All four hospital directors stated that their hospital staff were able to successfully repair minor issues, such as tubes, taps, and wires. However, both low-scoring hospitals experienced a major system breakdown and were not able to fix it themselves, thus their systems were no longer in operation. In addition to a major breakdown being one factor that led to a water treatment system becoming non-functional, lack of trained maintenance staff present at the hospital also contributed to this. As such, when a hospital experienced a major breakdown with their water treatment system, the hospitals were unable to find the necessary repair parts, as well as they lacked the capacity to fix it themselves. Both high-scoring hospitals had been able to repair any problems they had experienced throughout the course of the project.

Institutional Engagement

Sustaining safe water in HCFs requires sustained engagement by hospital staff. In the interviews, we examined this Institutional Engagement domain by asking about how the hospitals used the treated water, how they disseminated knowledge about the system to staff and patients, motivations for having safe water, and satisfaction and dissatisfaction with the treatment system from the perspective of both directors and patients.

The treated water at these four hospitals was used for a variety of purposes. Daily water usage at Thmar Kol hospital was highest in the internal medicine, pediatric, surgery, and emergency medicine wards. Some example uses of the treated water included handwashing, cleaning, and providing services to patients. Additionally, at Kampong Tralach and Kampong Thom hospitals the treated water was used for bathing and as drinking water for the staff.

Strategies for knowledge transfer about the water treatment system were present at both high-scoring hospitals, while in contrast, there were no strategies for knowledge transfer at either low-scoring hospital. There were both informal and formal strategies for transferring knowledge about the system to new and current staff were used at the high-scoring hospitals. Thmar Kol Hospital used word of mouth, while Kampong Tralach utilized the ward supervisors. Additionally, leadership at these high-scoring hospitals took an active role in reminding staff about how to take care of the treatment system and how to report maintenance issues. There were no mechanisms for transferring this type of knowledge at either low-scoring hospital. The maintenance personnel at

Kampong Thom had retired since the initiation of the project, and no other staff at the hospital had been trained to operate and maintain the system.

The high-scoring hospital directors expressed high motivation for having the water treatment system, primarily to help aid in receiving government funding for the hospital, while low-scoring hospital directors did not convey any strong motivation for having the system. Two of the hospitals expressed that the main motivation for having clean water came from the director's prioritization of a high Quality Improvement assessment score for the facility. Quality Improvement assessments were conducted every month by the MoH, in which the source and quality of water the hospital was using was included in the assessment. If the hospital was using clean water from a tap, they received a high score, and a high score resulted in the hospital receiving more government funding. The high-scoring hospital directors expressed being very motivated to have access to safe water at the hospital. Kampong Tralach's director stated, "water is life", and they needed clean water at the hospital for drinking. He also mentioned IPC as a motivating factor to have clean water at the hospital by explicitly stating that clean water reduced the rate of infection at the hospital. In contrast, the directors of the low-scoring hospitals did not appear to have any strong motivations for having safe water at the hospital. The director of Oudongk Hospital stated that as long as there is water, that is enough to provide services.

The directors of the high-scoring hospitals were satisfied with their water treatment systems, while the directors of the low-scoring hospitals were dissatisfied with their systems. Both directors of the high-scoring hospitals expressed satisfaction with the treatment system because the system saved them money, time, and reduced their workload as they no longer had to buy and transport clean water to their hospital.

"Before, I have a lot of headaches regarding the water problem in the hospital. During critical time, we called the water seller to transport us the water, while also seeking money to buy water. The water in every room was running weak, especially, in higher floor. The water is not clean, sometimes it contains mud and water plants. That was terrible. After obtaining water treatment system, it reduces much amount of my workload. I am extremely happy. We can use water freely without any concern."

-Hospital Director, Thmar Kol

Both directors also expressed wanting to continue using the system in the future and that they wanted to hook up more taps to the system. They wanted to use water freely without worrying about the quantity and quality of the water they were using to treat patients. In contrast, both of the low-scoring hospital directors described the water treatment system as a burden to the hospital because of the cost of supplies, such as chlorine and electricity, as well as the workforce needed to maintain the system.

"We pay double when the system was still in function. We still need water from water authority. The only work that water treatment system performed was to filter and dropped the chlorine, so we paid for electricity to keep it running, chlorine supply, hire staff to clean and maintaining the system. Overall, the water treatment system was not a relief, it was a burden to the hospital."

-Hospital Director, Kampong Thom

It was also noted by the director of Kampong Thom hospital that there was no value in the system when the hospital is located in a peri-urban area where they already have good access to the public water system.

From a patient perspective, during all four interviews the directors described how patients appeared dissatisfied with the system. This dissatisfaction was due to their distrust of tap water in general, regardless of whether there was an onsite water treatment system or not.

Discussion

The overall goal of this study was to conduct a follow-up evaluation to examine the sustainability of donated GE water treatment systems in nine Cambodian hospitals both during the two-year project and two years after the project period, as well as to identify barriers and facilitators to sustainability. Out of the nine hospitals assessed in this study, four hospitals had a working water treatment system at the time of the 2019 SWSM assessment while five hospitals had a broken or turned off system that was no longer in use. Overall, the water quality at the hospitals indicated that the water generally met WHO guidelines for drinking water. All sustainability domains across all hospitals had areas of improvement, but overall the technical feasibility and accountability domains received the highest scores, while the on-site capacity and institutional engagement domains were the lowest scoring. This study presents unique findings from sustainability and water quality data collected over a period of four years.

Water Quality

The water quality results, both microbiological and chemical, indicate whether or not the water treatment system was removing microbial contamination. The SWSM assessments in 2017 and 2019 showed a decline in the average scores for the sub-domain for water quality. The hospitals that reported having a broken water treatment system at the time of the 2019 assessment had higher concentrations of total coliforms and *E. coli* in their water samples than hospitals that reported working systems. Free chlorine levels at Kampong Thom started low and decreased further over the project period, as opposed to Kampong Trach and Oudongk where free chlorine levels started low and increased over the project period. These results indicate issues with chlorine dosing at the hospitals. At Kampong Thom and Kampong Trach hospitals, there were frequent periods documented when the chlorine doser was broken, which is a challenge that has been documented previously with on-site water treatment systems in Rwanda [37]. Oudongk and Kampong Trach hospitals had maximum *E. coli* concentrations of 13.6 MPN/100 mL and 6.3 MPN/100 mL respectively in their water samples. All three hospitals had high concentrations of total coliforms in their water samples, with Kampong Trach reaching levels of 136 MPN/100 mL, Kampong Thom at 166 MPN/100 mL, and Oudongk at 199 MPN/100 mL. Although all hospitals reported having access to chlorine, there seems to be a disconnect between having access to chlorine and having water samples with levels of free chlorine that met WHO guidelines – indicating that the chlorine may not have been purchased routinely or the staff did not perform the necessary tasks to ensure proper water treatment. It is also possible that the water became contaminated in the pipes from the water treatment system to the wards where the water samples were collected.

When looking at the temporal trends of the water quality by assessment year, we hypothesized that the low-scoring hospitals for the SWSM would show a decline in water quality. Kampong Thom and Bun Rany Hun Sen Hospitals, which were the two lowest scoring hospitals with treatment systems that were not working in 2019, did indeed experience a decline in water quality. Bun Rany Hun Sen Hospital had an increase in *E. coli* concentration from 2017 to 2019. In 2017, the sample that tested positive had an *E. coli* concentration of 1MPN/100mL, and in 2019 the *E. coli* concentration of the sample that tested positive was 48.3 MPN/100mL. Kampong Thom had a 330% increase in mean total coliforms concentration from 2015 to 2019. The ability of the hospitals to maintain and repair the system will ultimately affect the quality of the water. Both of these hospitals had sub-domain scores for maintenance and repair at or below the sustainability cut-off point of 2.0 which indicates that these hospitals lacked the capacity to repair and maintain their system.

Sustainability

We hypothesized that overall sustainability scores would increase each year at the hospitals, due to a growing understanding and comfort with the water treatment system, as well as increased institutional support. We found that all hospitals did in fact have an increase in the overall score from baseline to endline with eight out of nine hospitals showing a consistent increase each evaluation year, despite the fact that five out of nine treatment systems were reported to be not working at the time of the 2019 assessment. There is a seeming discrepancy between hospitals receiving high SWSM scores and non-functional systems, which we explore in the subsequent sections.

A study conducted by GEF and CGSW in Honduras and Ghana also used the SWSM to evaluate GE water treatment systems in HCFs and found a similar increase in scores over time. The study evaluated four hospitals in Honduras and six hospitals in Ghana [9]. All Honduran hospitals increased in score and had a similar average baseline assessment score of just above the sustainability cut-off at 2.1, similar to the 2.3 average baseline score presented in this study. In addition, the average overall sustainability score at the final assessment in Honduras was also similar at 3.3, close to the average of 3.0 measured in this study. In contrast, only two of the six Ghanaian hospitals had increased overall sustainability scores, and the initial average score for these hospitals was very low (1.8) and only reached an average of 2.0 at the final assessment [9]. In both Honduras and Ghana, the domain with the lowest score was technical feasibility, whereas in this study the lowest scores were in the on-site capacity and institutional engagement domains. The GEF donation program and the CGSW research team used the lessons learned from the study in Honduras and Ghana to improve upon hospital selection and technical aspects of the system in

Cambodia. This may explain the higher scores in the technical feasibility domain that were observed in this study.

Diving deeper into the factors that either enable or limit sustainability within the four domains is crucial to developing a holistic view of the sustainability of these systems. Additionally, this study showcased how the SWSM tool is able to effectively pinpoint the key areas of strengths and weaknesses for a given hospital's water treatment system and its sustainability. Once these strengths and weaknesses have been identified in specific domains and sub-domains, hospitals and key stakeholders can develop and implement targeted interventions and trainings at the hospital to improve the sustainability of the water treatment system. We will illustrate this point by examining each domain in detail and what was learned in the following sections.

Technical Feasibility

Technical feasibility was the highest scoring domain in the initial assessment and remained the top scoring domain in the midline and endline assessments as well. This was anticipated since emphasis was placed on technical feasibility requirements when the hospitals were selected for the donation program. Only hospitals that had consistent water and power supplies, as well as access to chlorine, were selected to participate in the donation program.

Scores for this domain remained high throughout the project despite the majority of systems being down because the only sub-domain that relies on the system working is the sub-domain for water quality which decreased from 2017 to 2019. Data for the sub-domain for plumbing infrastructure was not collected in 2019, possibly increasing the overall scores, thus having an impact on whether the sub-domain and domain scores are comparable across the different time points.

Hospitals with non-functional systems reported that the reason was due to issues with finding replacement parts, as well as a lack of capacity among the staff to fix the problem. This suggests that there is a need to improve the supply chain for replacement parts in order to facilitate local access. This is a well-documented issue in sustainability research on WASH infrastructure, from water supply (boreholes), to latrines, to water treatment systems (25, 28, 29, 35, 38). To ensure long-term benefits of safe water interventions in HCFs, appropriate technologies must be selected, such that replacement parts are widely available within close proximity to selected sites [40].

On-Site Capacity

On-site capacity was consistently one of the lowest scoring domains during each evaluation year. The average score for each of the four sub-domains in 2019 was either at, or below, the sustainability cut-off point, and the maintenance and repair and training sub-domains were the lowest scoring sub-domains.

The low average maintenance and repair scores for all three data collection points (1.1,1.2, and 1.7) are likely due to the hospitals not being able to access repair parts, thus why the majority of the treatment systems became non-functional. This finding highlights the connection between this sub-domain in the on-site capacity domain and the availability of supplies, parts, and equipment sub-domain in the technical feasibility domain. When hospitals are not able to find repair parts, the maintenance and repair of the system will consequently diminish. The interviews with the four hospital directors indicated that while they had access to minor replacement parts, such as tubes and wires, they did not have access to more complex parts.

In addition to not having access to these parts, the case study hospitals illustrated that they also did not have a staff member with the capacity to perform repairs. Consistent and ongoing training for staff is required for sustainability of the water treatment systems. The average sub-domain score for training remained at 2.0 for the first two evaluation years and dropped to 1.9 in 2019. Despite hospital leadership and Assist International focusing on technical training and capacity strengthening during the donor-supported period of the project, this capacity was not sustained once Assist International staff left in 2017. This issue of sustained on-site capacity was also documented in a study in Rwanda using similar membrane ultrafiltration water treatment systems that were donated to HCFs. The study found that during the donor-sponsored program, the HCF staff demonstrated the capacity to ensure daily maintenance activities were performed. However, an external implementing organization was shown to be needed to resolve system repair needs and supply materials [28]. To combat this issue of administrative changes and staff turnover, a WASH study that provided piped water supply to 25 HCFs in Rwanda provided refresher trainings on a yearly basis to ensure capacity retention. The final sustainability assessment conducted a year after project completion showed that all infrastructure built under the project was being well maintained and functional [42].

Financial and Operational Accountability

The average overall scores for the financial and operational accountability domain increased over the project period from 2.0 in 2016 to 3.5 in 2019. This 75% increase was the largest increase across all domains throughout the project. This increase was most notably from the increase in the sub-domain for external oversight which received an average score of 0 in the first assessment and 3.0 in the last. External oversight takes into account whether there is oversight from another entity, such as the MOH, for the water treatment system operation and maintenance or the water quality at the hospital. The increase in scores within the external oversight sub-domain aligns with the timeline for the Health Equity and Quality Improvement Project (H-EQUIP) rolled out by the MOH. H-EQUIP was started in 2016 and aimed to improve access to, and quality of, health services offered by HCFs through service delivery grants [44]. Quality improvement (QI) assessments are conducted on a monthly basis at HCFs by MOH staff, and a high score could result in more funding for that HCF. If a hospital has a piped water supply that is treated, the hospital will receive a higher score. The interviews with the case study hospitals revealed that the QI assessment provided them with motivation for system maintenance.

Budgeting was a high-scoring sub-domain for all assessment years, ending with a score of 4.0 across all the hospitals in 2019. WHO and USAID recommend that MOHs ensure that all HCFs have a budget for WASH [45,46], yet there was no MOH budget for WASH in HCFs in Cambodia at the time of this study. Despite none of the hospitals having a budget solely dedicated to WASH, all of the hospitals reported that they had enough money to fund the operation and maintenance of their water treatment system, with each hospital utilizing different funding mechanisms. A common theme in the case study hospitals was that the high-scoring hospitals utilized funds that were internally generated from patient fees, whereas the low-scoring hospitals relied on funds from patient fees along with government funding. There are many factors influencing why one hospital can generate adequate funds from patient fees and another hospital must rely on government funds. Factors such as the number of patients seen each month, the hospital's reputation for quality of care provided, and location of the hospital can affect revenue from patient fees. Thmar Kol was a high-scoring hospital that utilized patient fees to subsidize the operation and maintenance of the water treatment system. It is located in a relatively urban setting in the northern part of the country and reported serving an average of 700 outpatients per month. In contrast, Oudongk is a small, low-scoring hospital that relied on government funding to operate and maintain the water treatment system. It was in a more rural site in the north and reported seeing approximately 50 outpatients a month. More research is needed to fully understand the factors that affect the sub-domain for budgeting.

Internal oversight includes employee accountability and assigning key roles for maintenance and repair. Over the project period, the average score for this sub-domain increased from 2.5 at baseline to 3.1 at endline. However, there was a slight decrease in the average score in this sub-domain in 2017 down to 2.1. Again, this decline in a sub-domain score coincided with the time the responsibility for the water treatment systems transitioned from the donation program to the hospitals in 2017. But it is important to note that this sub-domain only decreased at the transition period, and then increased again by 2019, perhaps signifying that the hospitals were becoming more comfortable and familiar with the system. Three out of the four case study hospitals reported having maintenance and repair personnel for the water treatment system - either a dedicated contractor or this was designated as an additional role for current staff. A low-scoring case study hospital mentioned that one barrier to the system was not having the funds to hire a contractor to monitor the system, thus overburdening the current staff member. An overburdened staff may result in the treatment system becoming neglected, thus negatively affecting the sustainability. A disempowered workforce has been highlighted by WHO as a barrier to providing WASH in HCFs [6].

Institutional Engagement

Although institutional engagement increased over the project period from a baseline average score of 2.3 to an average score of 3.0 in 2019, this was one the lowest scoring domains in 2019. Staff awareness and support, along with ownership, were sub-domains where the average scores decreased in 2019.

Based on the case study findings, the level of engagement from hospital leadership with the water treatment system appeared to influence the level of awareness and commitment of staff and patients to the system. At low-scoring hospitals, the leadership took a less active role in informing staff about the system, whereas the leadership at the high-scoring hospitals were more engaged and discussed the system at monthly staff meetings. Increased engagement by the hospital leadership led to the staff promoting the safe water to patients and utilizing the treated water more. A high level of engagement from leadership has been shown to increase sustainability of WASH infrastructure in schools in Kenya [38]. The school's management involved new teachers in WASH-related activities, as well as conducted community education, latrine construction, and purchased WASH supplies [38]. This level of engagement from leadership was a characteristic of the schools who had sustained the activities under the Safe Water System Intervention 2.5 years after implementation [38].

Despite the good water quality results, there were reports of dissatisfaction from patients and staff towards the treated water at all hospitals. Patients reported distrust with drinking the water from the treatment systems at all four case study hospitals. Additionally, when the site visits were conducted in 2019, researchers observed that bottled water was being sold at every hospital, despite signs above the water taps stating that the water was safe to drink. These reports of distrust of the provided tap water may represent generations of skepticism towards public water supply, stemming from historical events. Public water supplies were damaged during the Khmer Rouge regime in the late 1970's, prompting all Cambodians to start boiling water for consumption. Drinking tap water remains an uncommon practice across the country of Cambodia, and the tap water at these hospitals, although treated and safe, was no exception. While these treatment systems will benefit hospitals by providing safe water for hygiene purposes, the findings of this study illustrate that many hurdles remain in gaining patient trust towards the treated drinking water.

Study Strengths and Limitations

The SWSM tool used in this study was improved upon based on previous field studies, therefore the improvements to this tool allowed for a greater assessment of the critical aspects contributing to sustainability. Additionally, this tool was specifically designed to assess sustainability of the GE water treatment systems, therefore giving the study more accurate and specific findings. The use of a structured and systematic protocol for data collection provided more consistent data and allowed for comparison of results both within hospitals over time and across hospital sites. Moreover, data collection occurred at multiple time points during and after the project by trained project staff, allowing for indicators to be compared over time. Actual water quality data was collected, including microbiological assessment of water quality, as well as chlorine and turbidity data. Lastly, the qualitative data collection allowed for a more in-depth, explanatory analysis of sustainability for the treatment systems.

A major weakness of the study is that the results may not be generalizable to other types of water treatment systems since the tool is specifically tailored to GE water treatment systems. Additionally, this study only tells us about the barriers and facilitators to sustainability that these nine HCFs in Cambodia operating a GE water treatment system faced. Therefore, the results may not be generalizable to other hospitals in Cambodia, or to HCFs in other countries. Furthermore, a lack of funding as well as a lack of project staff to collect water samples led to a different method being used for microbiological water testing in 2019 (Aquagenx) compared to the previous microbiological analyses by the IDEXX Quantitray method used for water quality testing during the project period. The use of these different methods limits the comparison of microbiological water quality results between the project period and the 2019 follow-up assessment – in particular because the Aquagenx method is only semi-quantitative compared to the IDEXX method. This also means that there was no chlorine or turbidity data for 2019. An additional limitation was that the water samples were not consistently collected from the same locations within the hospital for each hospital and across time points, making it difficult to compare trends in water quality and have comprehensive understanding of water quality throughout the hospital and at the water source. Sub-domain data for plumbing infrastructure within the technical feasibility domain was not collected for in the 2019 SWSM assessment, which limits the ability to compare the domain scores across evaluation years.

Finally, due to limited resources, project staff were only able to interview the directors at four of the nine study hospitals. By only interviewing four hospital directors, saturation was not reached in this study and instead a case study approach was taken for interpreting results. It is possible that if more hospitals were interviewed, more examples of barriers and facilitators would have been exposed. Although these four interviews provided valuable insights about the hospitals' experiences with the water treatment systems, the original intention was to interview all hospital directors in order to identify common themes and reach saturation.

Study Implications and Recommendations

The barriers and facilitators identified in this study are similar to those identified in Honduran HCFs operating a GE water treatment system [9]. Barriers such as a lack of continuity of communication and training of staff, a poor supply chain to access repair parts, and a lack of monitoring and record keeping were identified by both studies. As for facilitators, HCFs in Honduras and Cambodia all had sufficient funds for the system by utilizing both internally generated and government funding streams.

The SWSM tool should be applied to other settings with HCFs operating different types of water treatment systems in order to assess whether these are common barriers and facilitators or unique to the GE water treatment systems. Additionally, this research can fill the gap in literature and help to develop a more thorough understanding of the impact and sustainability of safe water provision in HCFs in LMIC settings. The following are actionable next steps that researchers and practitioners should consider for future water treatment system projects based on the study findings and are organized by each of the four domains of sustainability:

Technical Feasibility

- Collaborate with local vendors to develop a district-level supply chain for more complex replacement parts. This will ensure that selected sites have local access to critical parts, thus eliminating this barrier to sustainability.
- Standardize water sample collection activities for assessment, including methods used and the number of samples taken at each hospital. Consider collecting samples of water before the treatment systems were installed so there is a better comparison sample.

Accountability

- Advocate with regional and national governments to establish a budget for WASH in HCFs.
- Work with hospital leadership to create a standardized monitoring plan to enhance the hospital's capacity, as well as to ensure that routine tasks for system maintenance are completed.

Institutional Engagement

- Develop a communications plan about the safe water at the hospital and deliver it to the local communities who utilize the hospital. Increased awareness around the system will ultimately improve consumption of the water, thus improving the motivation to sustain the access to safe, reliable water for staff and patients.
- Conduct a training of trainers for leadership on how to continually engage and educate staff about the system.

On-Site Capacity

- Provide yearly refresher courses to the study hospitals to ensure that maintenance personnel are up to date with procedures. This will ensure that staff turnaround does not affect the operation and maintenance of the water treatment system, and there will always be a staff member at the hospital who can repair and maintain the system.
- In addition to having a dedicated staff member for system repairs at each hospital, an additional position should be created at regional or national level governments for when the capacity for procuring spare parts and conducting repairs exceeds that of the HCFs.

Conclusion

The SWSM assessments generated increased sustainability scores despite the majority of systems being non-functional because this tool takes many factors into account that contribute to sustainability. Overall, most of the study hospitals lacked the capacity to obtain spare parts and make repairs to the water treatment systems which was reflected in the number of non-functional systems observed in the endline assessment. However, the hospitals remained motivated to provide safe water to the hospital and had the money to do so, thus exhibiting some aspects of an enabling environment for sustainability. The study results indicate that access to parts and the capacity to perform repairs were the main barriers to the sustainability of the treatment systems, while hospitals having sufficient funding for the system and motivated leadership were the main facilitators to an enabling environment for sustainability.

Some barriers to sustainability can be addressed at the hospital level, such as increased oversight, increased monitoring and system awareness, while other barriers need to be addressed by the regional and national level governments. Barriers such as a lack of a WASH budget, poor hospital infrastructure, and a lack of consistent WASH in HCF standards are beyond the scope of the individual facilities and need to come from governments to ensure sustainable WASH infrastructure. Lastly, barriers such as supply chain issues are unique to each HCF and need to be taken into consideration by project implementers when conducting initial needs assessments and planning the intervention.

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Appendices

Appendix 1: Master SWSM Scoring Metric

Domain	Subdomain	Indicator	Scoring	Calculations	Director Form	Maintenance Form	Staff Form	Observation Form	Water Quality Form
Technical Feasibility	Water Quantity and Availability	Flow Interruption Frequency	0 = every day	Average the two variables	X	X			
		Flow Interruption Duration	0 = a week or more	Average the two variables	X	X			
		Cause of Flow Interruption	0 = no 1 = yes Any response in "other" (d,e) = 1	Sum of A-E ques. scores: 0 = 4+ yes responses 1 = 3 yes responses 2 = 2 yes responses 3 = 1 yes response 4 = 0 yes response	X	X			
		Alternative Sources of Water	0 = no	Direct score	X	X			
		Mixing of Water	0 = yes	Direct score	X	X			
	Availability of Supplies, Parts, and Equipment	Supplies for water treatment	0 = no	Direct score	X	X			
		Water Treatment System	0 = no	Average the two variables	X	X			
		Water Infrastructure Parts	0 = no	Direct score	X	X			
		Other Equipment	0 = no	Direct score	X	X			
	Plumbing Infrastructure	Plumbing (Observation)	0 = < 50% 1 = 50-74% 2 = 75-84% 3 = 85-94% 4 = < 95%	Direct score				X	
		Water Quality – Microbiological 1 (TC)	[illegible]	Direct score					X
On-Site Capacity	Communication	Communication 1	0 = Disagree	Direct score	X				
		Communication 2	0 = Disagree	Direct score	X				
		Communication 3	0 = Disagree	Direct score		X			
		Communication 4	0 = Disagree	Direct score		X			
	Operation	Operational Tasks	0 = Rarely	Direct score		X			
	Preventative Maintenance and Repair	Preventative Maintenance 1	0 = Never or more than 1 year	Direct score		X			
		Preventative Maintenance 2	0 = Never or more than 1 year	Direct score		X			
		Renewal, replacement, and	0 = few problems	Direct score	X				
		Renewal, replacement and	0 = few problems	Direct score		X			
	Training	Training 1	0 = No, never	Direct score	X				
		Training 2	0 = No, never	Direct score		X			
Financial and Operational Accountability	Internal Oversight	Employee Accountability	0 = no	Sum of A-D scores:	X	X			
		Assignment of Key Roles 1	0 = no	Direct score	X				
		Assignment of Key Roles 2	0 = no	Direct score	X				
		Assignment of Key Roles 3	0 = no	Direct score	X				
	External Oversight	Oversight by Another Entity	0 = no	Direct score	X				
	Budgeting	Supplies for water treatment	0 = yes	Direct score	X				
		Parts/Equipment for water treatment	0 = yes	Direct score	X				
		Parts for water infrastructure	0 = yes	Direct score	X				
		Other Equipment	0 = yes	Direct score	X				

Domain	Subdomain	Indicator	Variable Name	Scoring	Calculations	Director Form	Maintenance Form	Staff Form
Institutional Engagement	Staff Awareness and	Water Treatment System Awareness	water_treatment_system_awareness	0 = no	Average of score from staff			X
	Staff Participation in Use of Treated Water	Treated Water for Drinking	treated_water_for_drinking	0 = Never 1 = Only when there is no other option 2 = Sometimes 3 = Most of the time 4 = Always	Average of score from staff, director and maintenance	X	X	X
		Treated Water for Hygiene	treated_water_for_hygiene	0 = Never 1 = Only when there is no other option 2 = Sometimes 3 = Most of the time 4 = Always	Average of score from staff, director and maintenance	X	X	X
		Treated Water for Medical Purposes	treated_water_for_medical_purposes	0 = Never 1 = Only when there is no other option 2 = Sometimes 3 = Most of the time 4 = Always	Average of score from staff and director	X		X
	Satisfaction	Satisfaction of Director	satisfaction_of_dr_list.dr_satisfaction_of_	0 = Disagree	Sum of A-D scores:	X		
		Satisfaction of Maintenance 1	satisfaction_of_maintenance_list.mn_satisf	1= Disagree	Sum of A-D scores:		X	
		Satisfaction of Staff 1	satisfaction_of_staff_tap	0 = Disagree	Average of score from staff and	X	X	X
		Satisfaction of Staff 2	satisfaction_of_staff_flow	0 = Disagree	Average of score from staff and	X	X	X
		Satisfaction of Staff 3	satisfaction_of_staff_quality	0 = Very poor quality	Average of score from staff and		X	
	Ownership	Ownership	ownership_list.dr_ownership (a-d)	0 = Disagree	Sum of A-D scores:	X		

Appendix 2: Full scoring guide for all hospitals

	Baray Santuk			Kg Thom		
	1st	2nd	3rd	1st	2nd	3rd
Overall Score	**2.3**	**2.8**		**2.2**	**2.5**	**3.0**
Domain Scores						
Technical Feasability	3.0	3.4		2.9	3.0	3.7
On-site Capacity	2.3	2.4		1.8	1.9	1.6
Financial & Operational Accountability	1.8	2.0		1.8	2.0	4.0
Institutional Engagement	2.0	3.5		2.4	3.2	2.8
Subdomain Scores						
Water Quantity and Availability	2.9	4.0		3.0	4.0	3.0
Availability of Supplies, Parts, and Equipment	3.3	2.7		2.8	2.5	4.0
Plumbing Intrastructure	2.0	3.0		4.0	4.0	x
Water Quality	3.7	4.0		1.7	1.3	4.0
Communication	4.0	2.5		3.4	2.5	2.0
Operation	2.0	4.0		1.0	2.0	2.0
Preventative Maintenance and Repair	1.0	1.0		1.0	1.0	0.7
Training	2.0	2.0		2.0	2.0	2.0
Internal Oversight	2.5	2.0		1.8	2.0	4.0
External Oversight	0.0	0.0		0.0	0.0	x
Budgeting	3.0	4.0		3.5	4.0	x
Staff Awareness and Support	2.2	3.3		2.4	2.5	2.0
Staff Participation in Use of Treated Water	1.5	3.1		2.0	3.1	3.0
Satisfaction	3.2	3.7		3.0	3.2	3.3
Ownership	1.0	4.0		2.0	4.0	x

	Kg Trach			Kg Tralach		
	1st	2nd	3rd	1st	2nd	3rd
Overall Score	**2.5**	**2.9**	**3.2**	**2.5**	**2.7**	**3.3**
Domain Scores						
Technical Feasability	2.8	3.5	4.0	2.8	3.0	4.0
On-site Capacity	2.8	2.5	2.5	2.6	2.3	2.3
Financial & Operational Accountability	2.2	2.3	3.3	2.3	2.0	4.0
Institutional Engagement	2.3	3.2	2.8	2.2	3.4	3.1
Subdomain Scores						
Water Quantity and Availability	3.4	4.0	4.0	3.6	4.0	4.0
Availability of Supplies, Parts, and Equipment	3.0	3.0	4.0	2.0	3.3	4.0
Plumbing Intrastructure	2.0	3.0	x	2.0	2.0	x
Water Quality	2.7	4.0	4.0	3.7	2.7	4.0
Communication	3.0	1.5	3.0	3.5	2.0	3.0
Operation	4.0	4.0	4.0	4.0	4.0	2.0
Preventative Maintenance and Repair	1.0	2.5	2.0	1.0	1.0	2.0
Training	3.0	2.0	1.0	2.0	2.0	2.0
Internal Oversight	2.6	3.0	2.0	2.8	2.0	4.0
External Oversight	0.0	0.0	4.0	0.0	4.0	4.0
Budgeting	4.0	4.0	4.0	4.0	4.0	4.0
Staff Awareness and Support	1.3	2.5	1.3	2.0	3.3	1.5
Staff Participation in Use of Treated Water	2.1	2.8	3.0	2.2	3.1	3.1
Satisfaction	2.8	3.5	2.8	3.5	3.3	3.6
Ownership	3.0	4.0	4.0	1.0	4.0	4.0

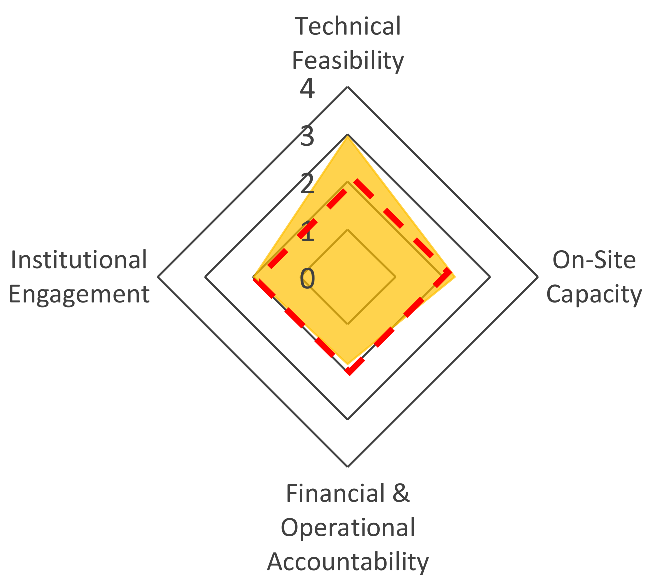
	Koh Thom			Oudong		
	1st	2nd	3rd	1st	2nd	3rd
Overall Score	**2.2**	**3.0**	**3.3**	**2.5**	**2.9**	**2.7**
Domain Scores						
Technical Feasability	2.7	3.6	3.7	3.1	3.6	2.3
On-site Capacity	1.9	2.5	1.9	2.4	2.8	2.0
Financial & Operational Accountability	1.6	2.3	4.0	2.3	2.0	3.3
Institutional Engagement	2.7	3.4	3.5	2.3	3.0	3.2
Subdomain Scores						
Water Quantity and Availability	3.3	4.0	3.0	4.0	4.0	3.5
Availability of Supplies, Parts, and Equipment	2.5	3.5	4.0	2.0	3.5	3.5
Plumbing Intrastructure	1.0	3.0	x	4.0	3.0	x
Water Quality	4.0	4.0	x	2.3	4.0	0.0
Communication	4.0	3.0	2.5	2.5	4.0	2.0
Operation	1.0	4.0	2.0	4.0	4.0	2.0
Preventative Maintenance and Repair	0.8	1.0	1.0	1.0	1.0	2.0
Training	2.0	2.0	2.0	2.0	2.0	2.0
Internal Oversight	1.8	2.8	4.0	3.0	2.9	2.0
External Oversight	0.0	0.0	4.0	0.0	0.0	4.0
Budgeting	3.0	4.0	4.0	4.0	3.0	4.0
Staff Awareness and Support	3.0	2.5	3.0	1.8	2.0	2.5
Staff Participation in Use of Treated Water	3.3	3.7	3.2	1.8	2.7	2.8
Satisfaction	2.7	3.5	3.6	3.4	3.4	3.5
Ownership	2.0	4.0	4.0	2.0	4.0	4.0

	Sampov Lun			Thmar Kol			Bun Rany Hun Sen	
	1st	2nd	3rd	1st	2nd	3rd	1st	3rd
Overall Score	**2.4**	**2.7**	**3.1**	**2.4**	**2.6**	**3.4**	**2.0**	**2.4**
Domain Scores								
Technical Feasability	2.6	3.5	3.0	2.8	3.4	3.7	2.1	3.5
On-site Capacity	2.1	2.4	2.1	2.1	2.5	2.8	2.8	2.0
Financial & Operational Accountability	2.3	1.7	4.0	2.1	1.6	4.0	1.2	1.7
Institutional Engagement	2.5	3.0	3.2	2.7	3.0	3.1	1.9	2.4
Subdomain Scores								
Water Quantity and Availability	3.2	4.0	4.0	3.3	4.0	4.0	3.3	3.0
Availability of Supplies, Parts, and Equipment	2.0	3.5	4.0	2.3	4.0	4.0	2.5	4.0
Plumbing Intrastructure	2.0	3.0	x	4.0	4.0	x	1.0	
Water Quality	3.0	3.7	1.0	1.7	2.7	3.0	1.7	
Communication	2.5	2.5	2.5	3.5	3.0	3.0	3.0	2.0
Operation	4.0	4.0	2.0	2.0	4.0	4.0	4.0	
Preventative Maintenance and Repair	1.0	1.0	2.0	1.0	1.0	2.0	2.0	2.0
Training	1.0	2.0	2.0	2.0	2.0	2.0	2.0	
Internal Oversight	3.0	1.0	4.0	2.4	0.9	4.0	2.4	1.0
External Oversight	0.0	0.0	4.0	0.0	0.0	4.0	0.0	0.0
Budgeting	4.0	4.0	4.0	4.0	4.0	4.0	1.3	4.0
Staff Awareness and Support	2.3	1.8	2.0	2.1	2.8	2.0	1.0	1.5
Staff Participation in Use of Treated Water	3.1	3.0	3.2	3.3	2.8	2.9	2.0	2.7
Satisfaction	2.5	3.3	3.6	3.4	3.3	3.6	2.7	3.5
Ownership	2.0	4.0	4.0	2.0	4.0	4.0	2.0	2.0

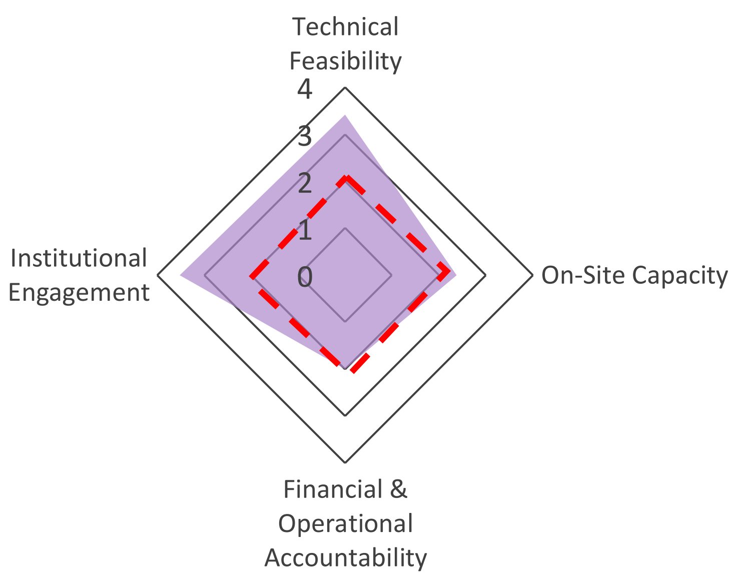
Appendix 3: Comparison of Domain Scores per Hospital

3a. Baray Santuk Hospital – Sustainability Domain Scores 2015 vs. 2017

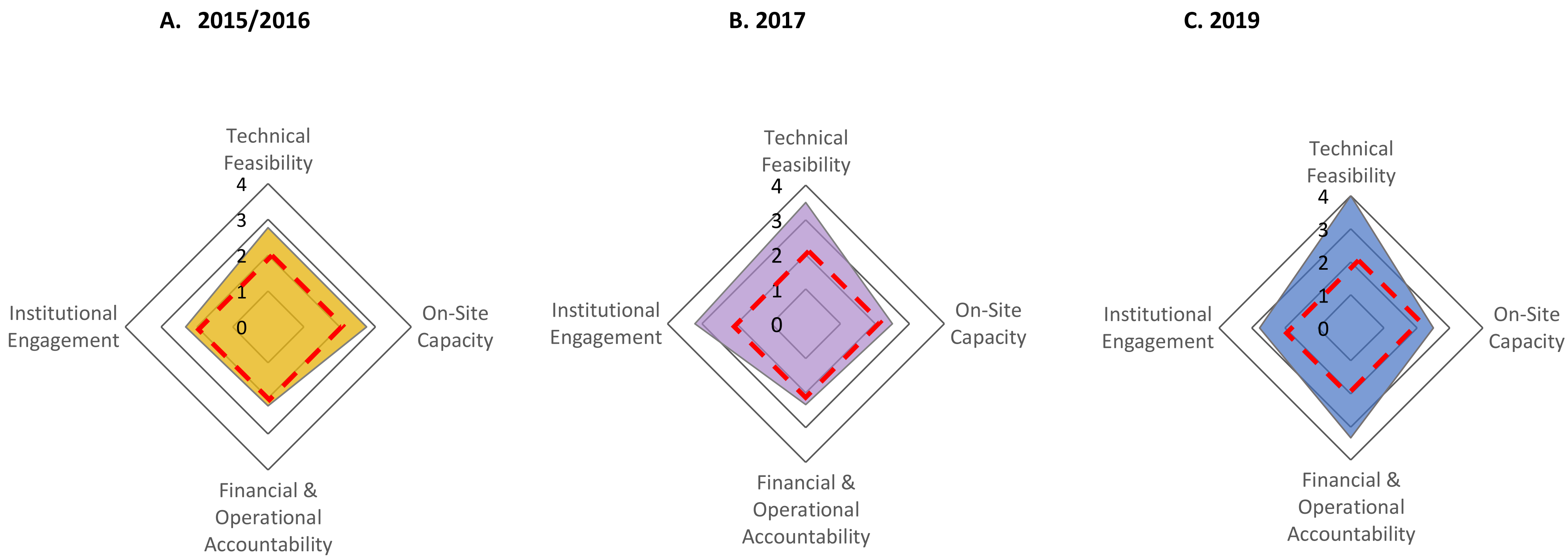
A. 2015/2016



B. 2017

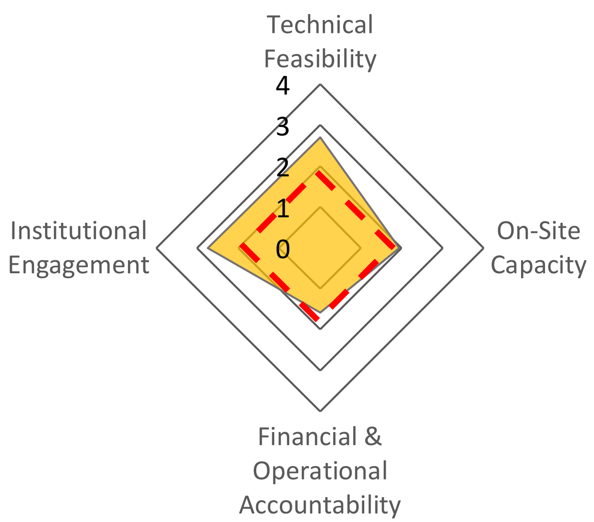


3b. Kampong Trach Hospital – Sustainability Domain Scores 2015/2016 vs. 2017 vs. 2019

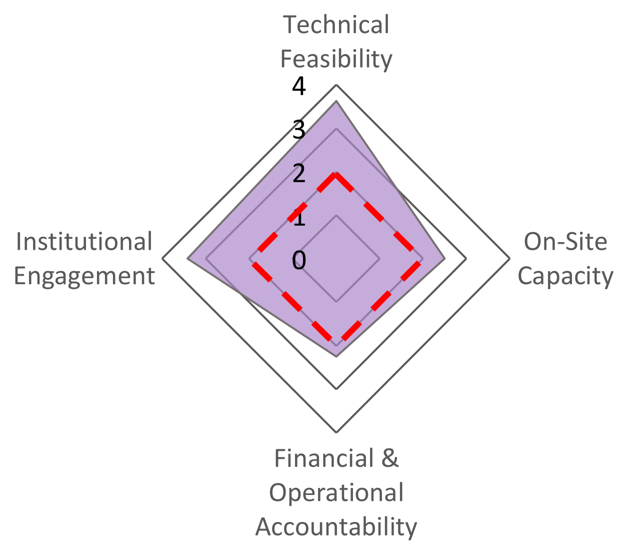


3c. Koh Thom Hospital – Sustainability Domain Scores 2015/2016 vs. 2017 vs. 2019

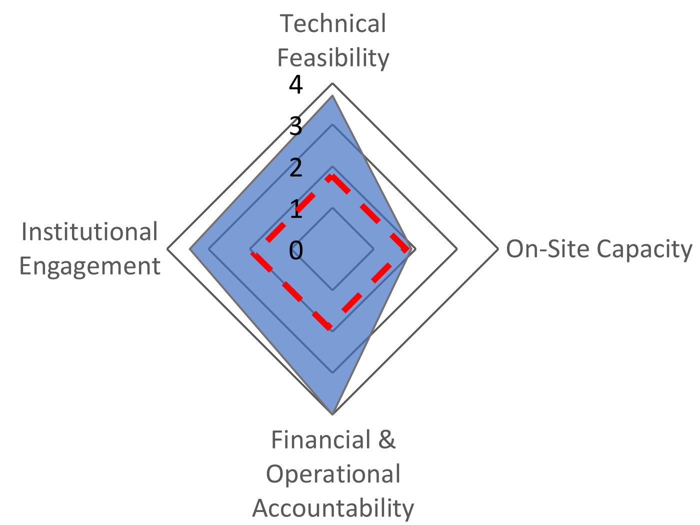
A. 2015/2016



B.2017

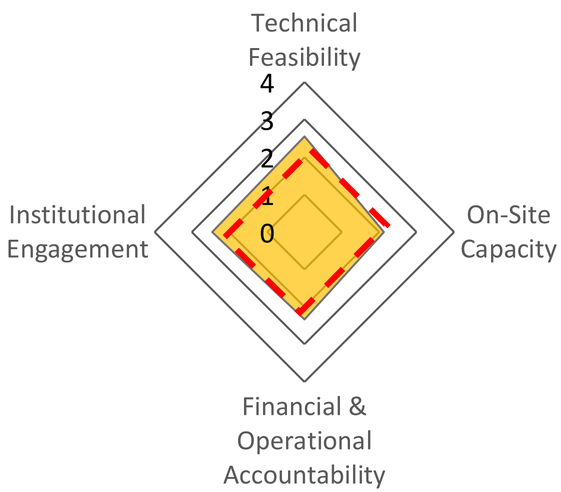


C.2019

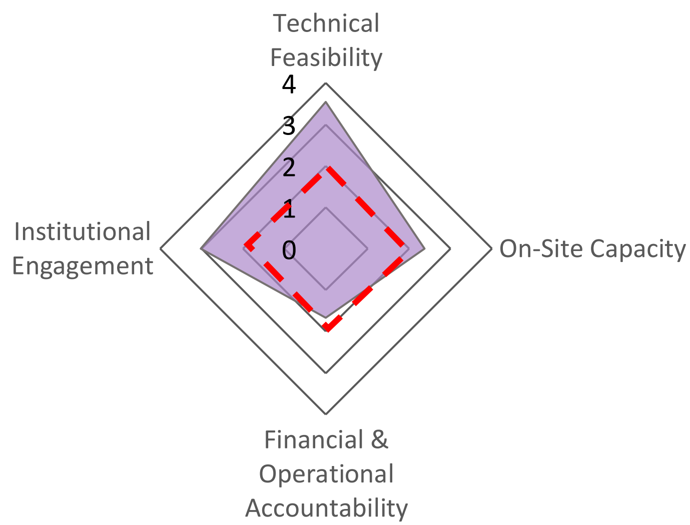


3d. Sampov Lun Hospital – Sustainability Domain Scores 2015/2016 vs. 2017 vs. 2019

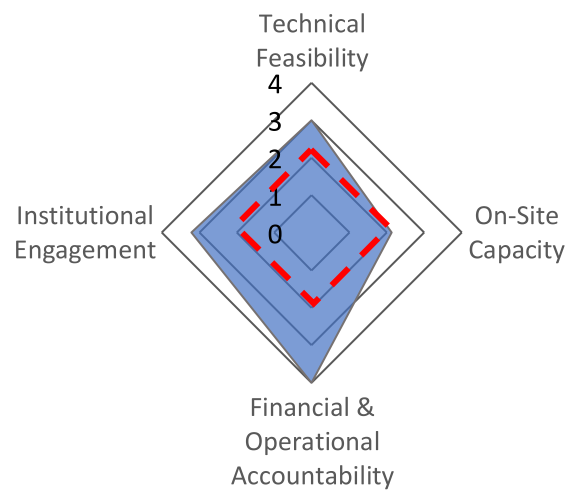
A. 2015/2016



B. 2019

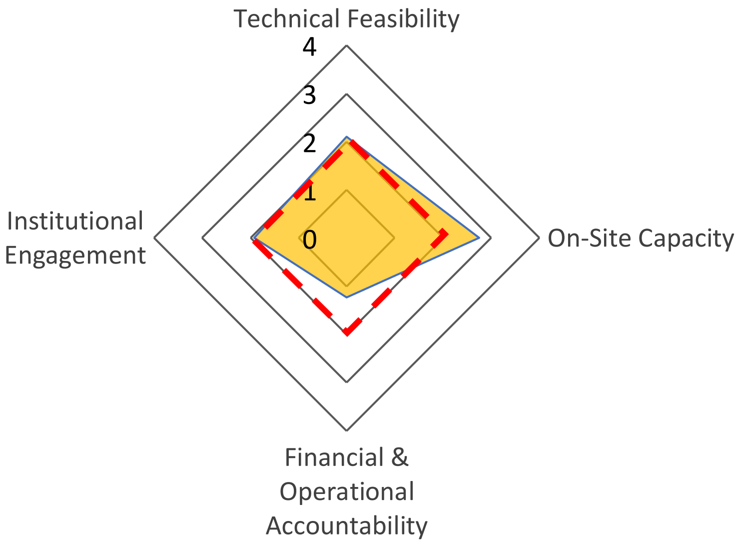


C. 2019

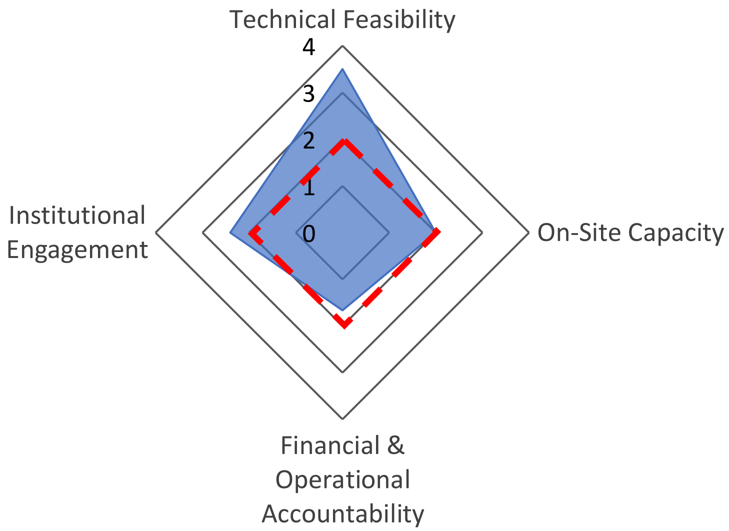


3e. Bun Rany Hun Sen Hospital – Sustainability Domain Scores 2015/2016 vs. 2019

A. 2015/2016

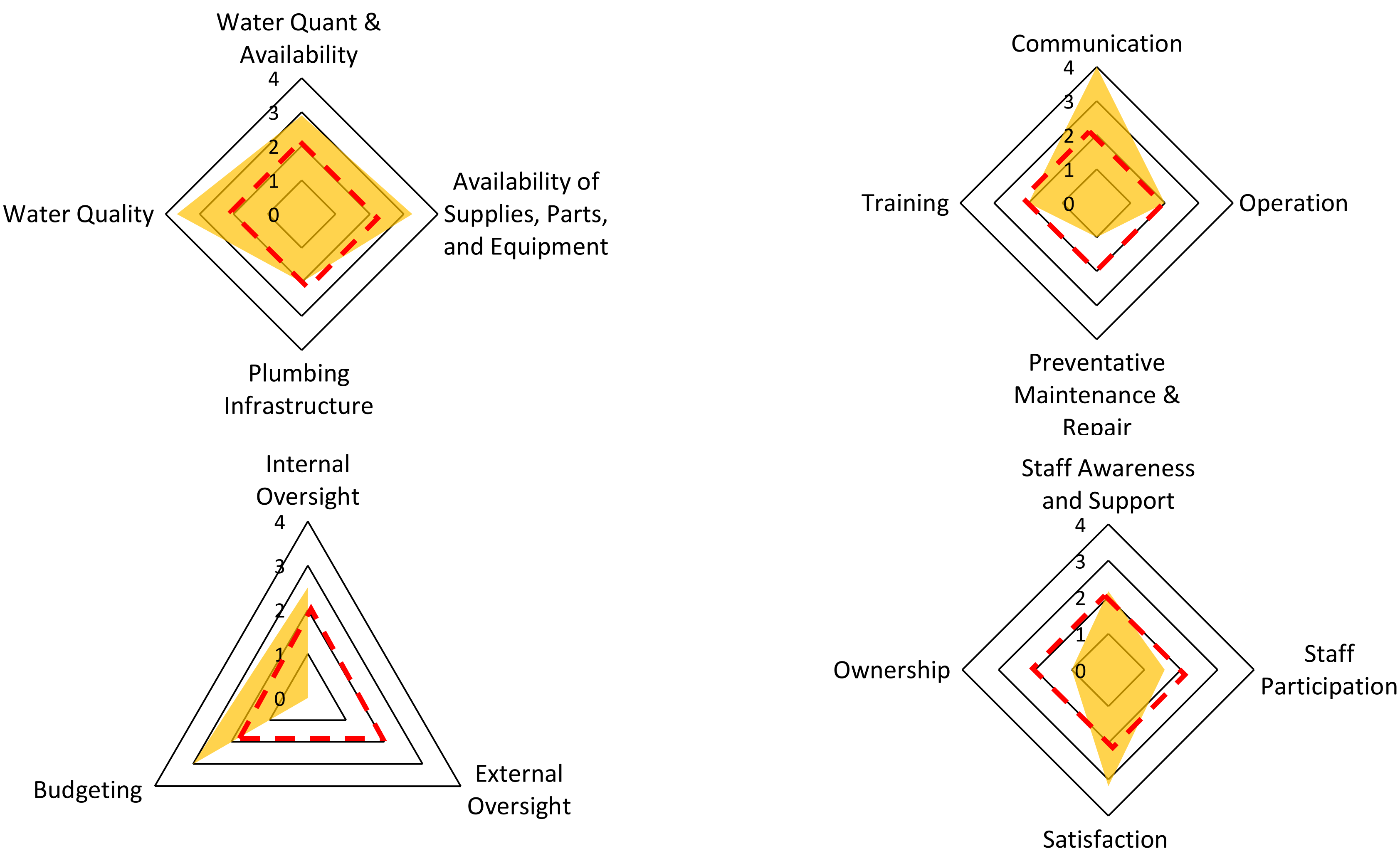


B. 2019

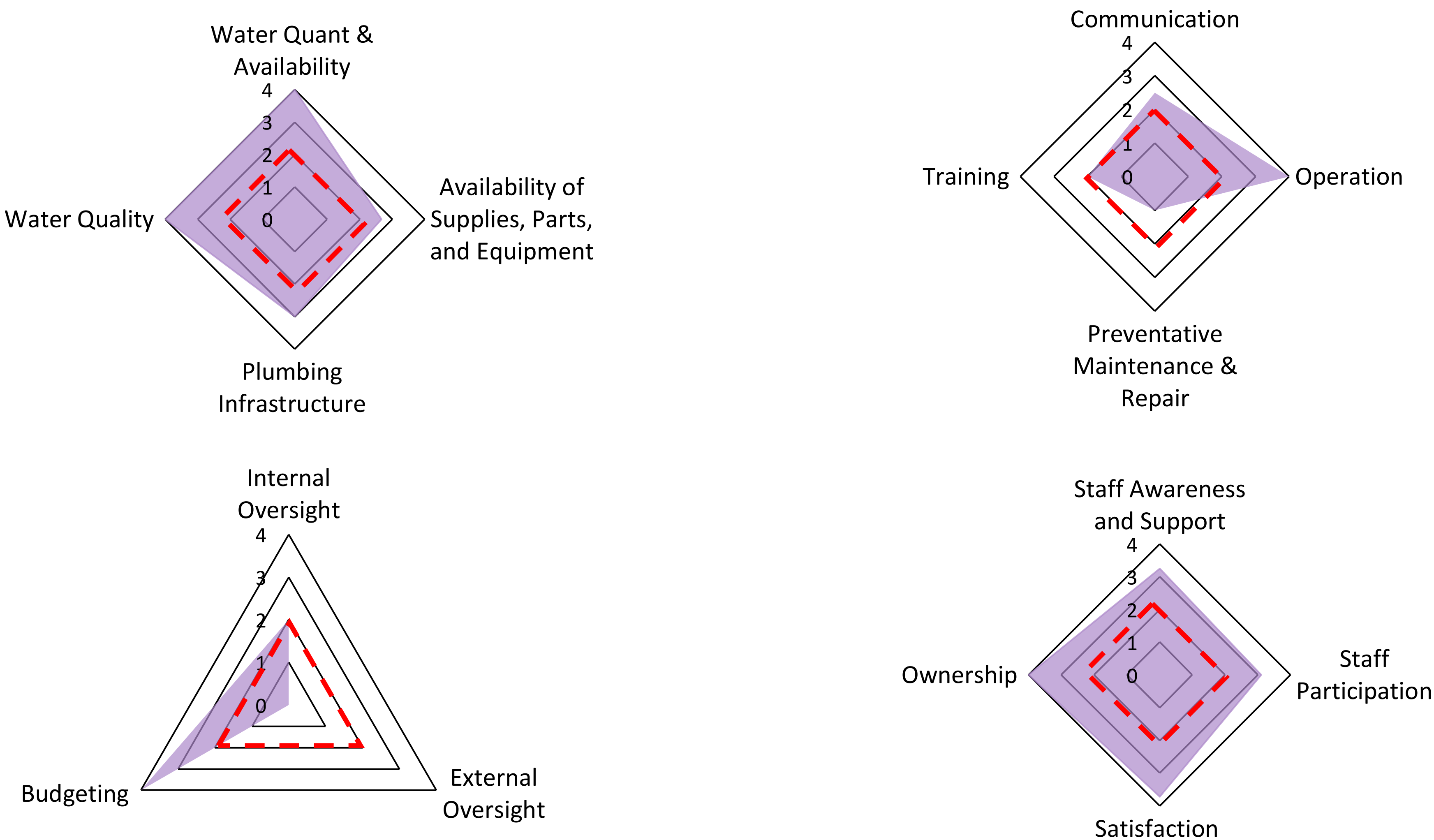


Appendix 4. Sub-domain Sustainability Scores for all Hospitals

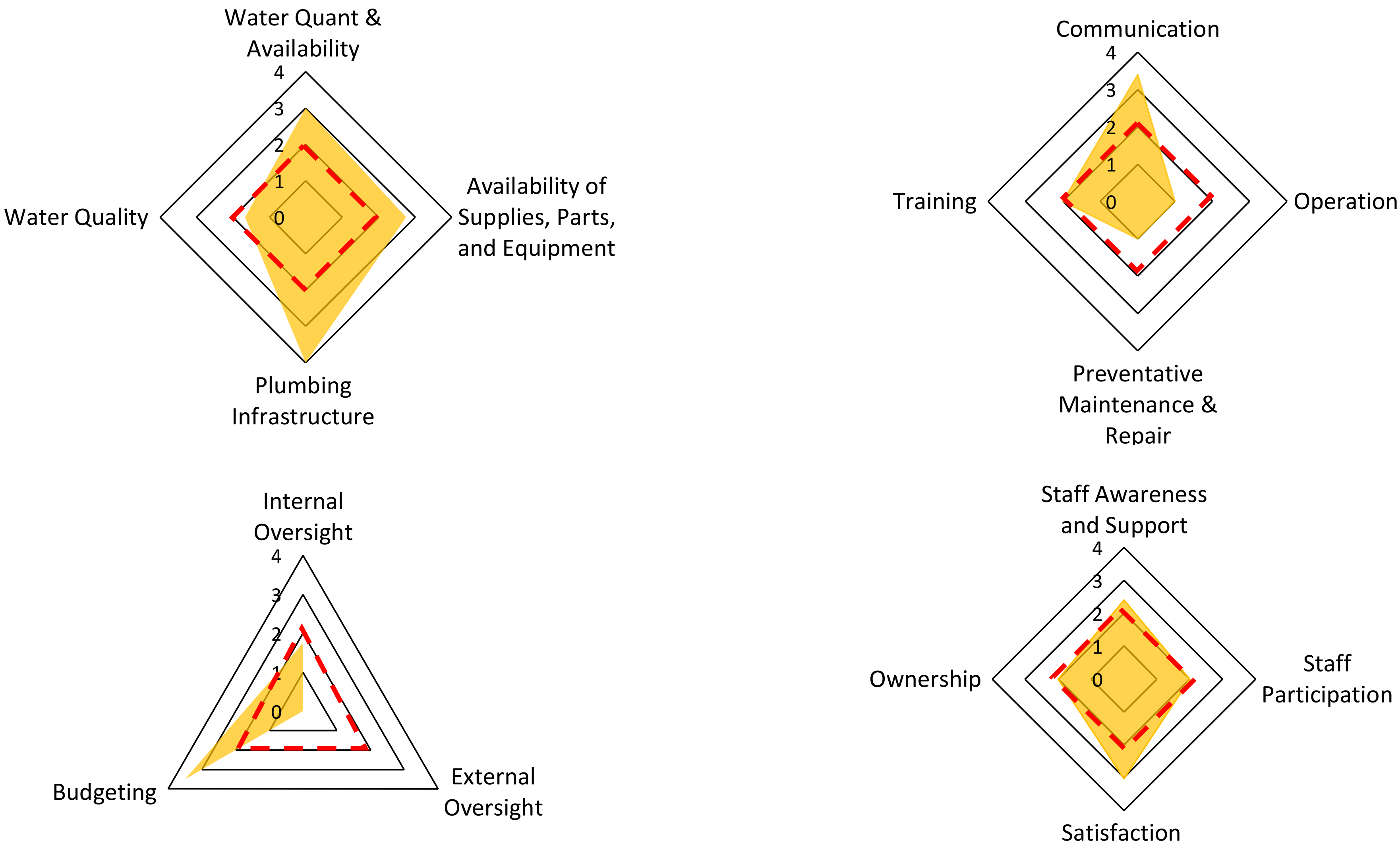
4a. Baray Santuk 2015/2016 Sub-domain sustainability scores



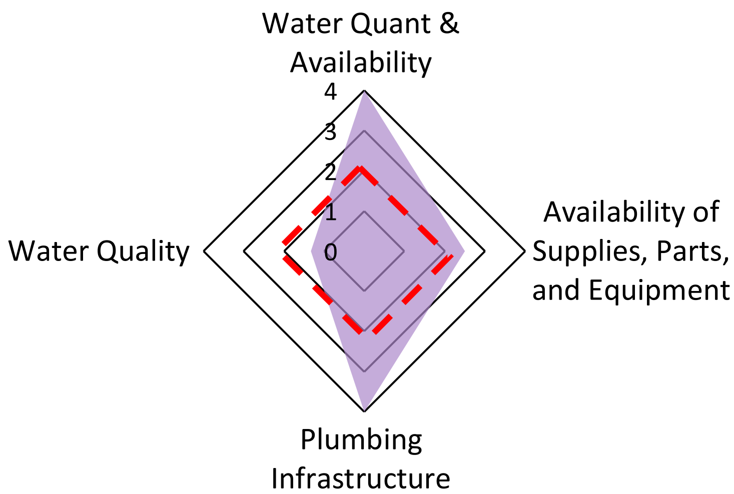
4b. Baray Santuk 2017 Sub-domain sustainability scores

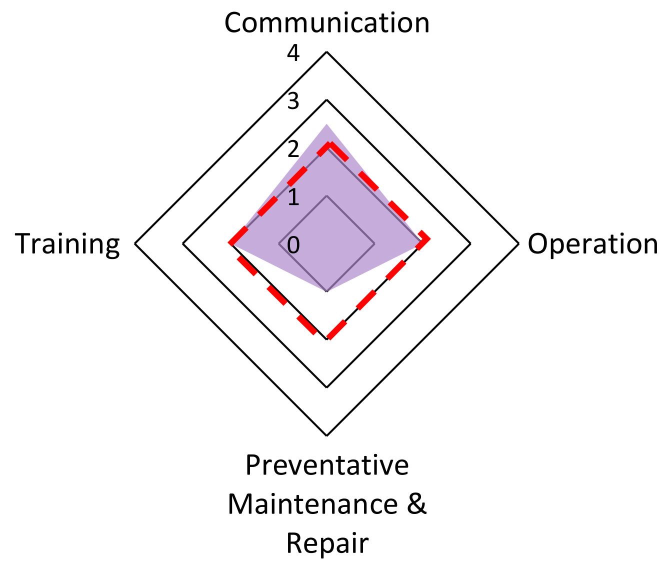


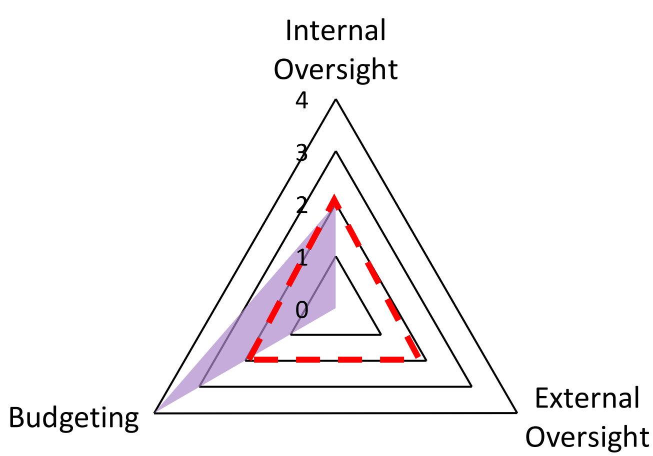
4c. Kampong Thom 2015/2016 Sub-domain sustainability scores

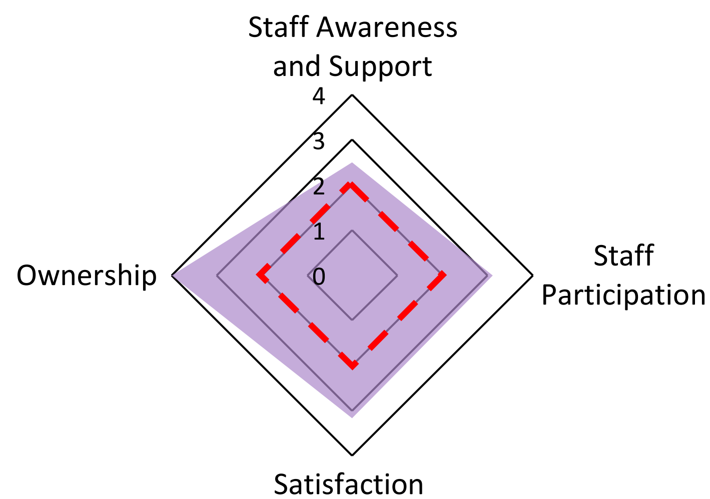


4d. Kampong Thom 2017 Sub-domain sustainability scores

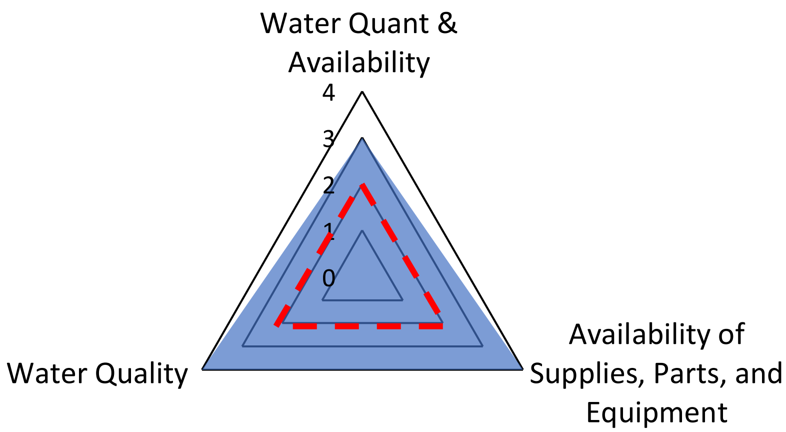


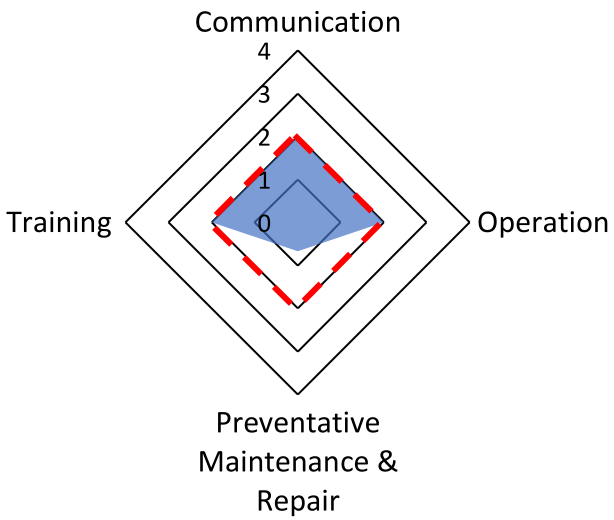


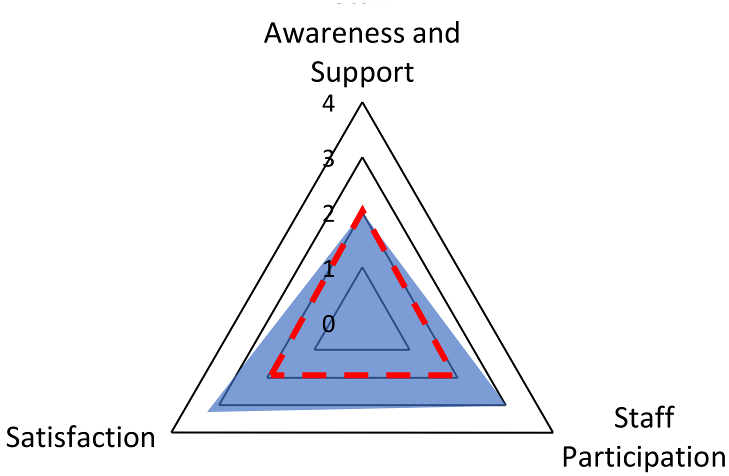




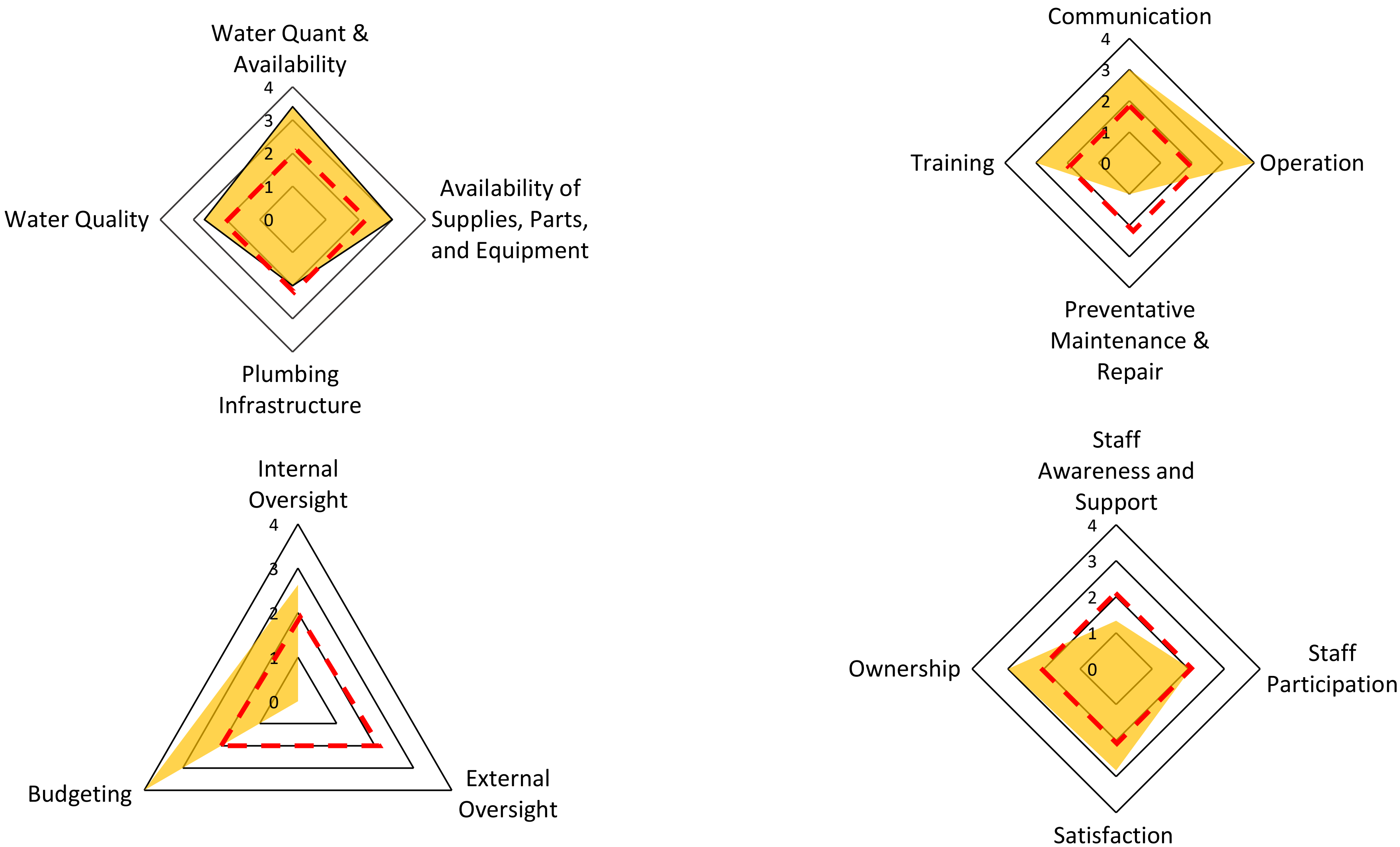
4e. Kampong Thom 2019 Sub-domain sustainability scores



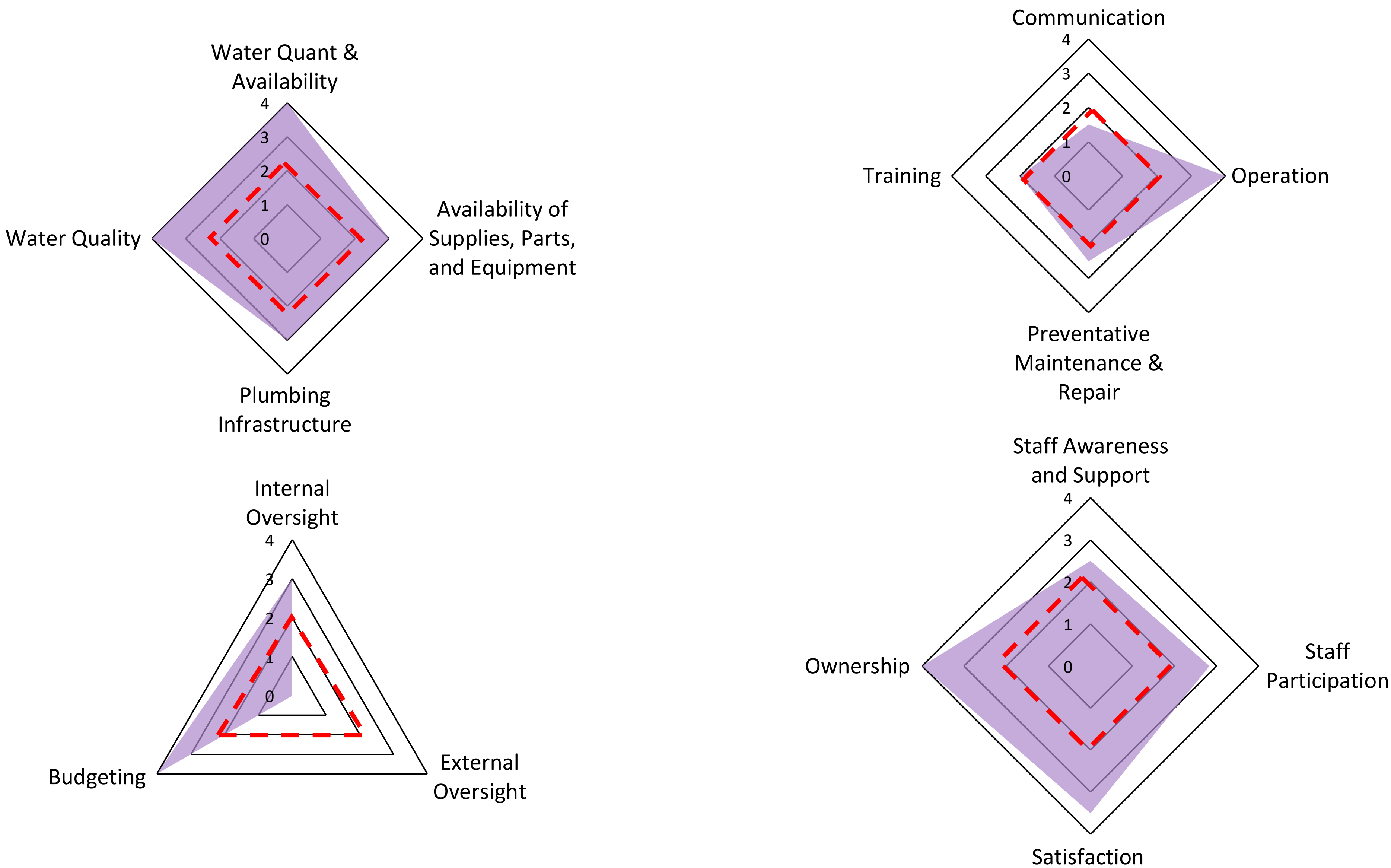




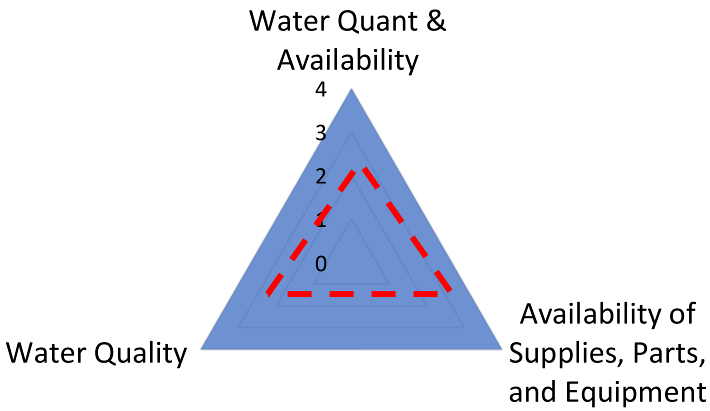
4f. Kampong Trach 2015/2016 Sub-domain sustainability scores

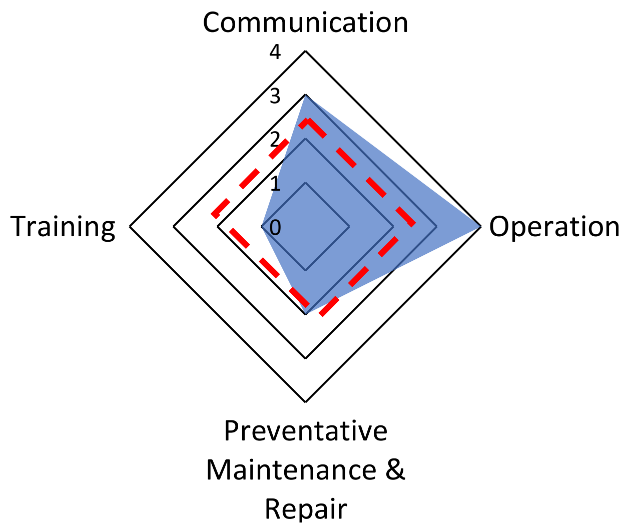


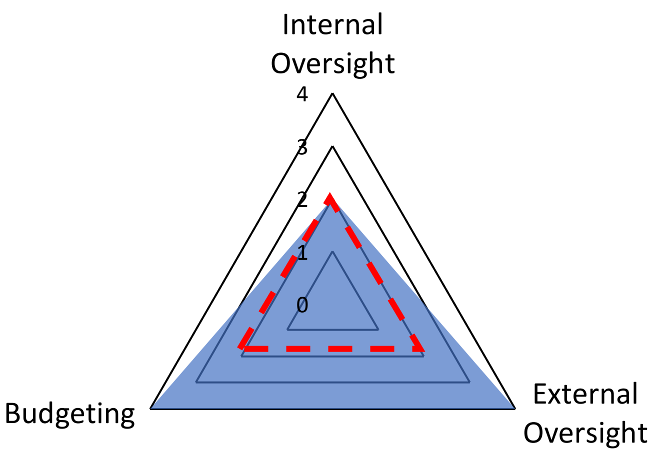
4g. Kampong Trach 2017 Sub-domain sustainability scores

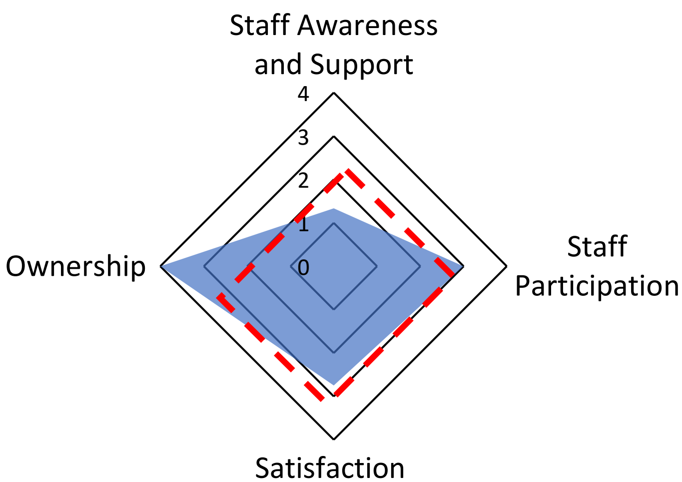


4h. Kampong Trach 2019 Sub-domain sustainability scores

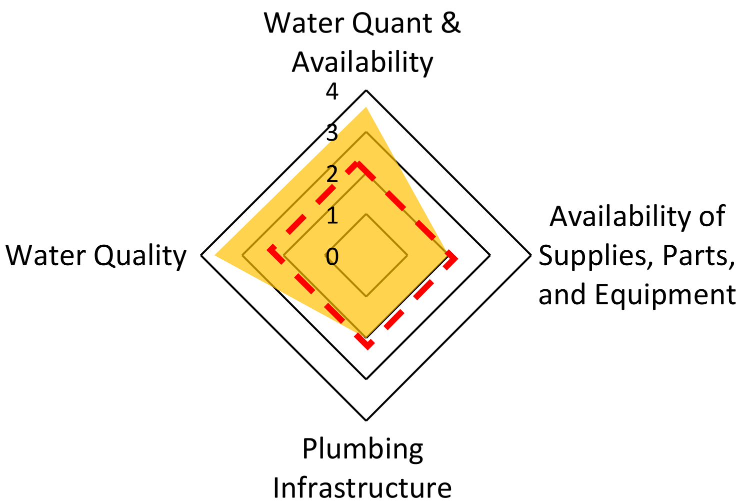


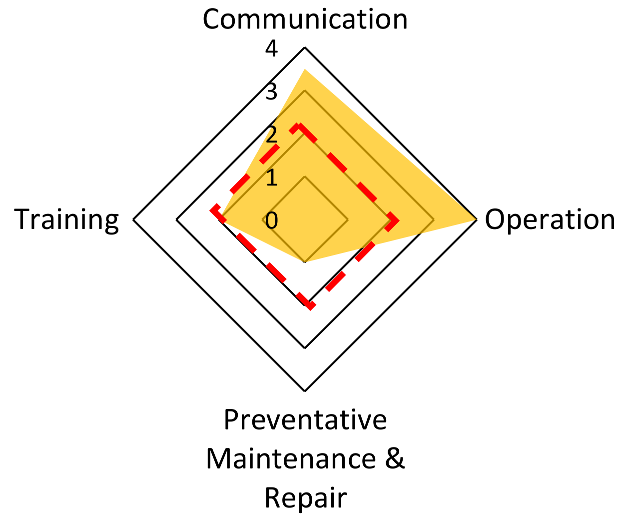


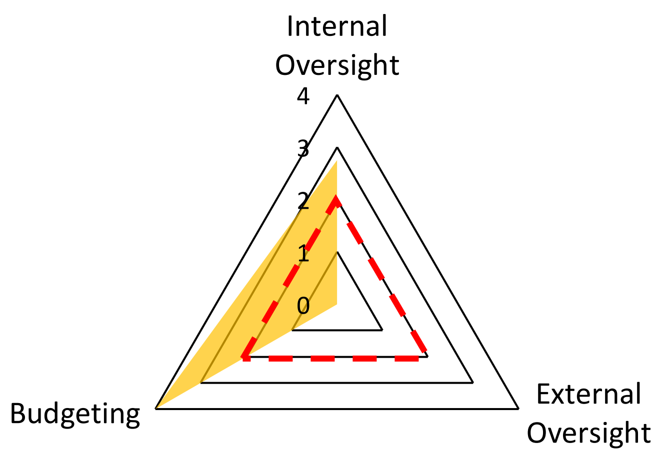


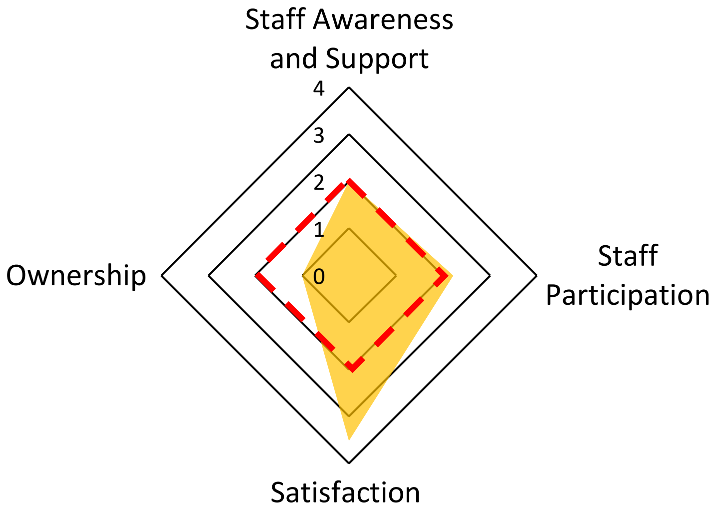


4i. Kampong Tralach 2015/2016 Sub-domain sustainability scores

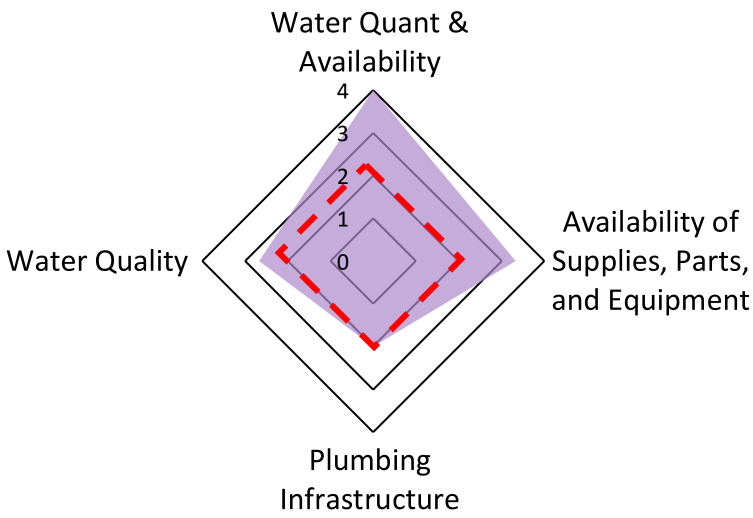


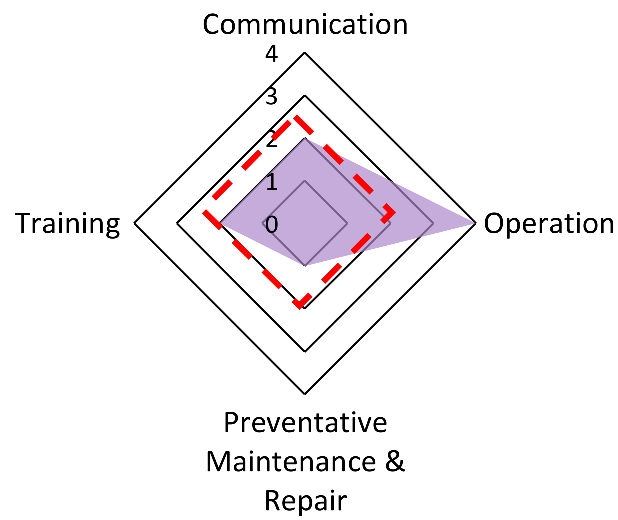


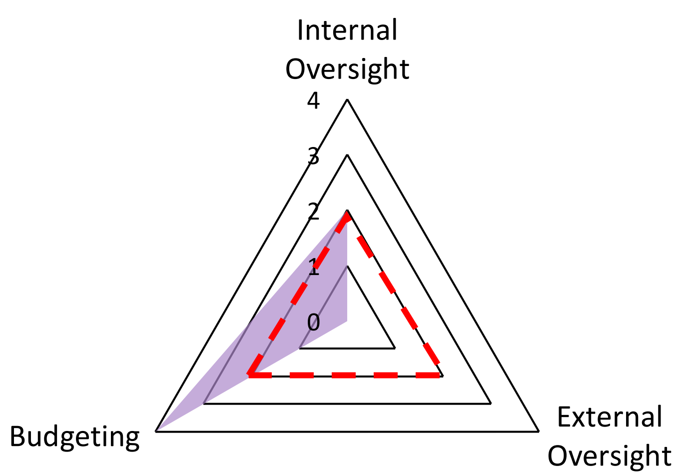


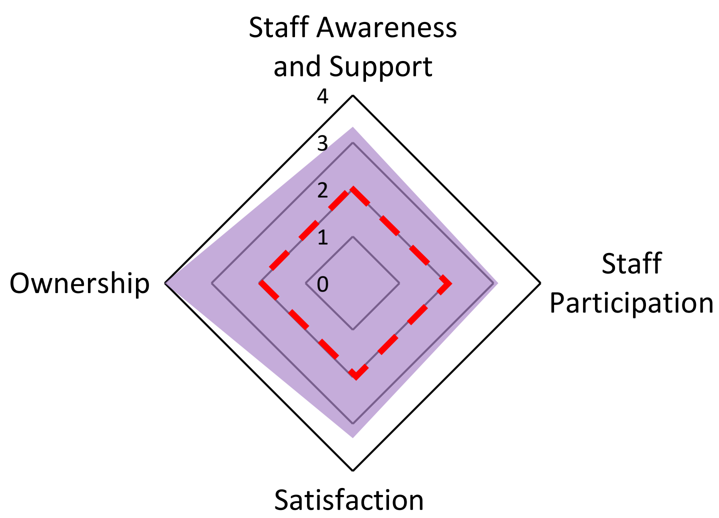


4j. Kampong Tralach 2017 Sub-domain sustainability scores

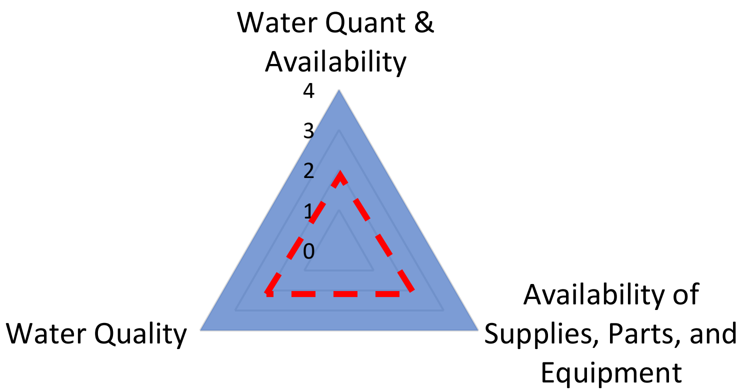


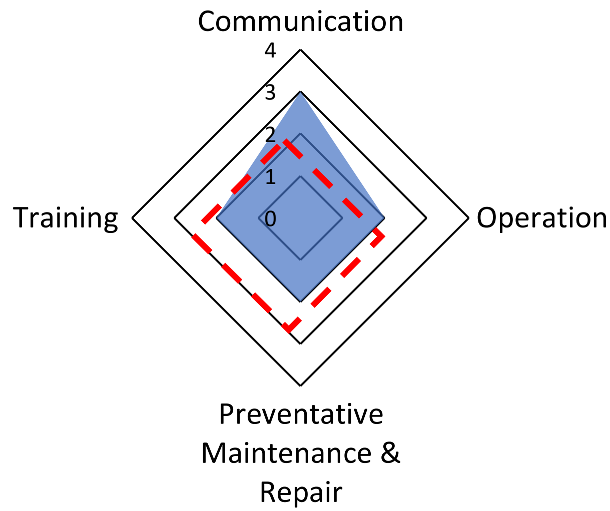


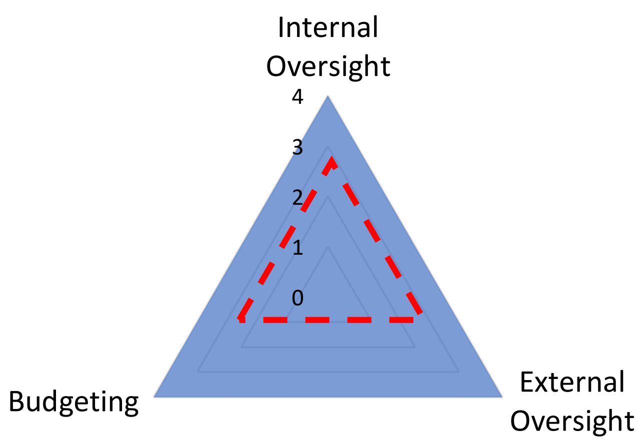


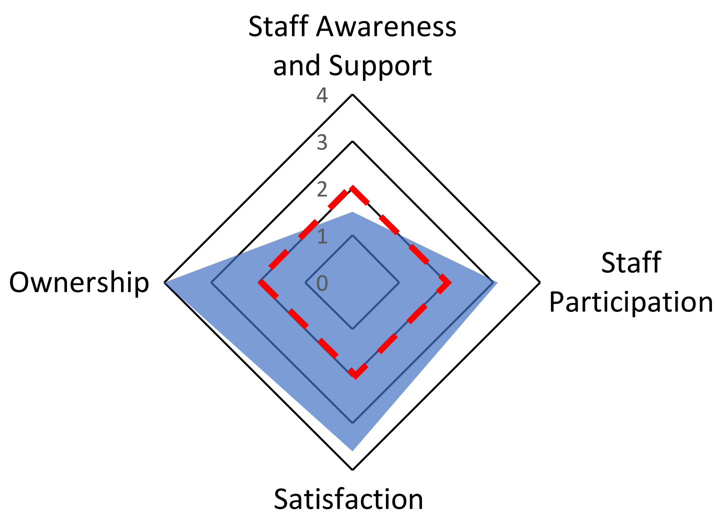


4k. Kampong Tralach 2019 Sub-domain sustainability scores

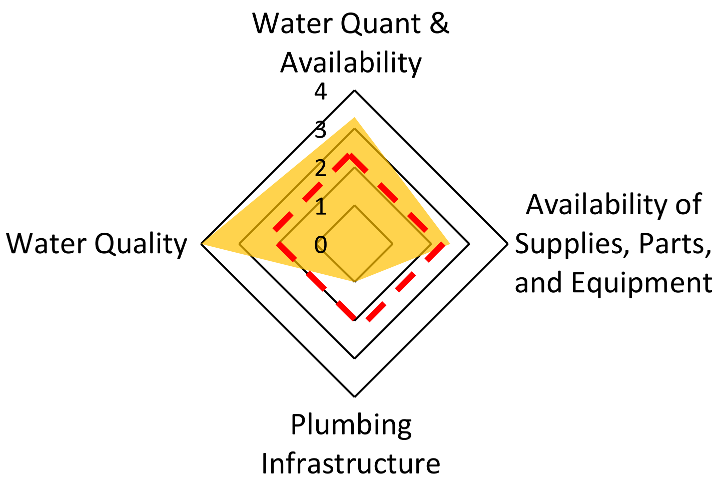


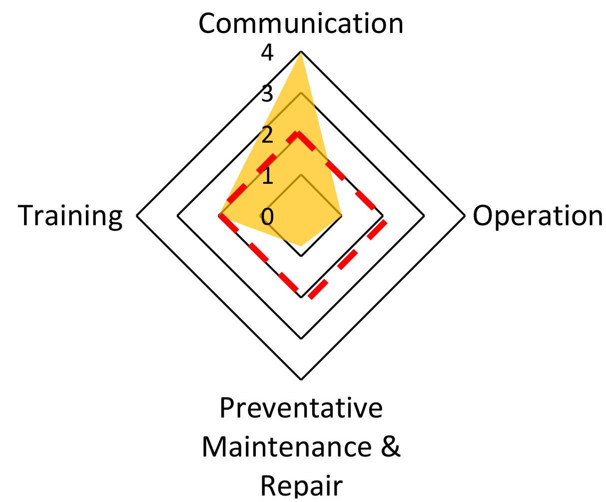


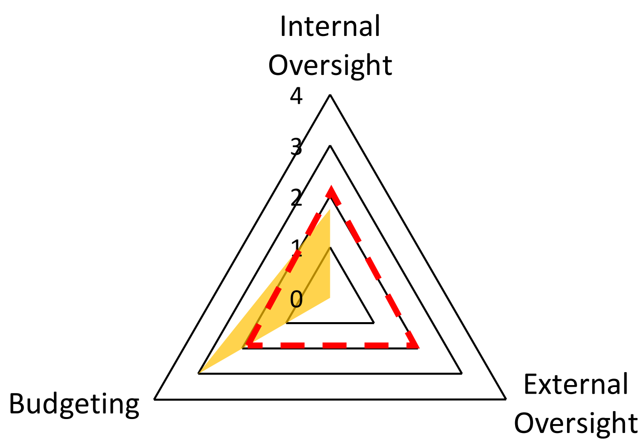


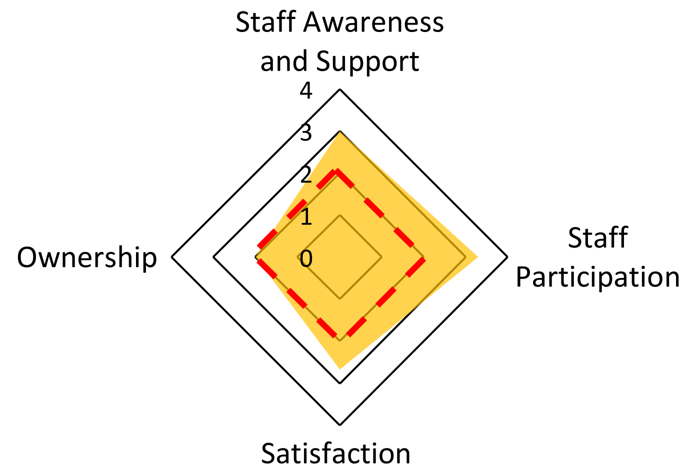


4l. Koh Thom 2015/2016 Sub-domain sustainability scores

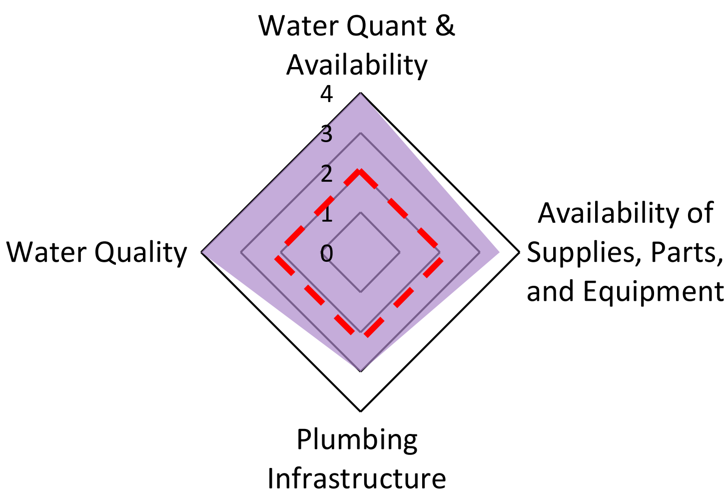


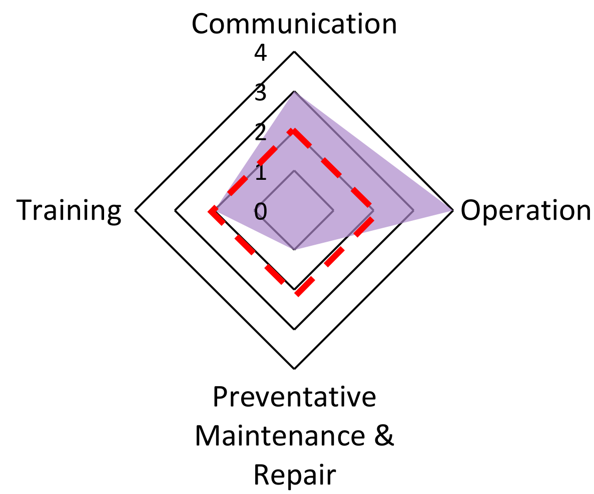


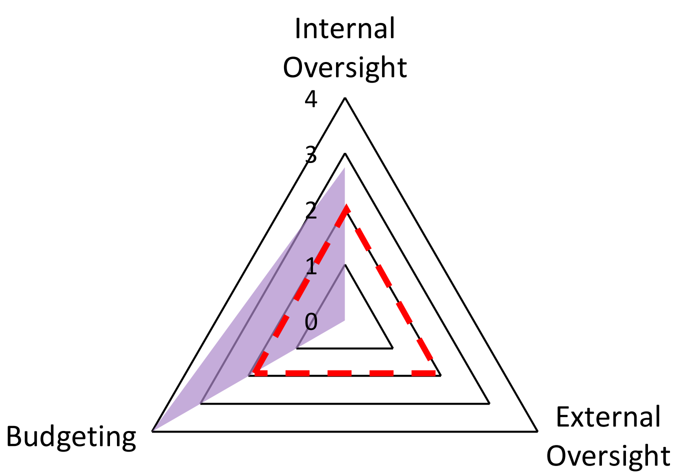


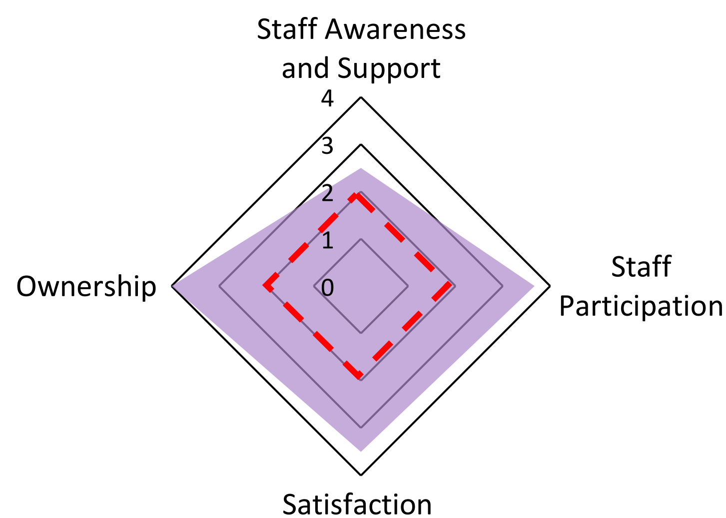


4m. Koh Thom 2017 Sub-domain sustainability scores

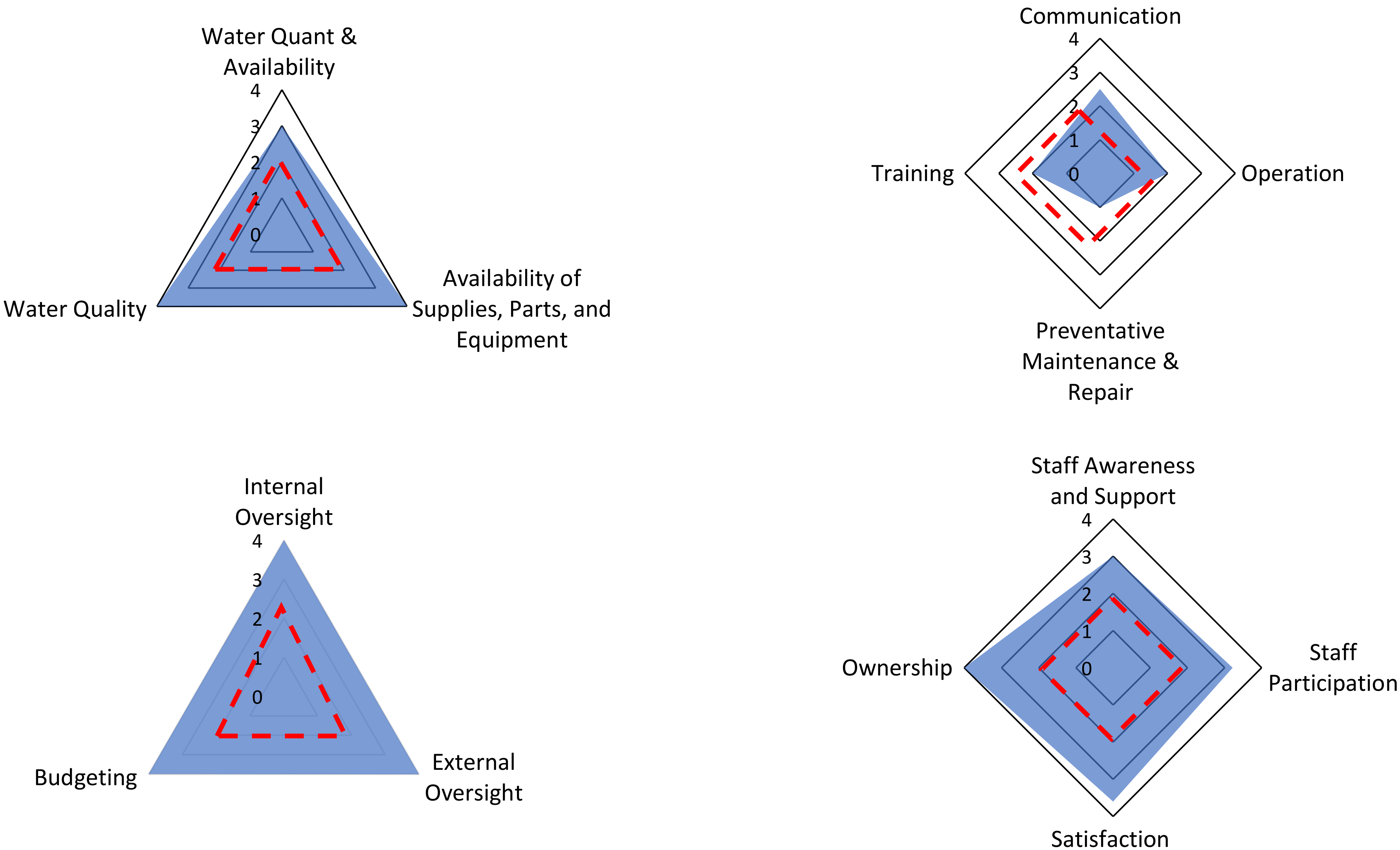




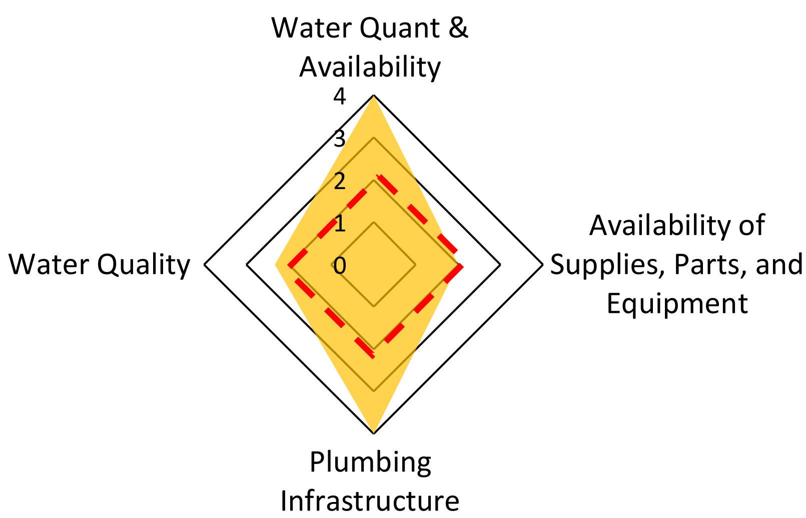


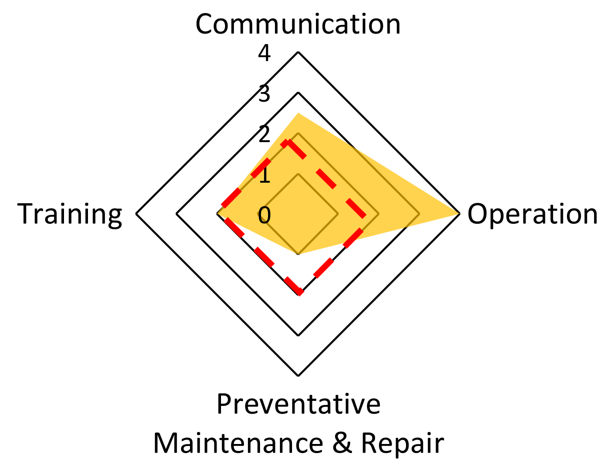


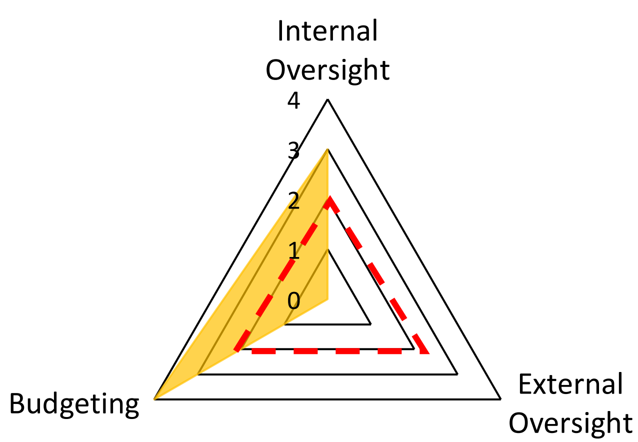
4n. Koh Thom 2019 Sub-domain sustainability scores

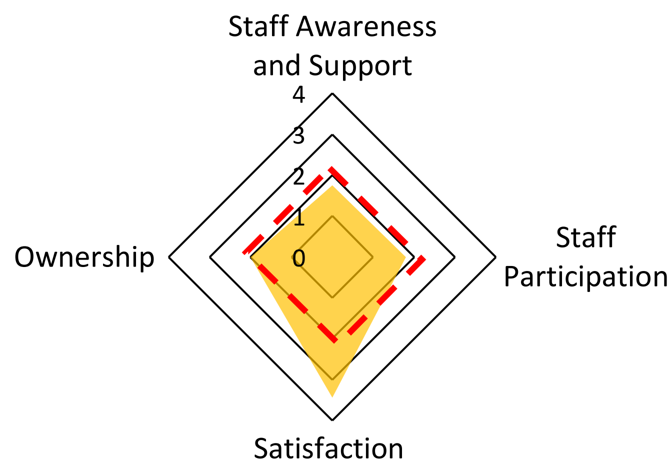


4o. Oudongk 2015/2016 Sub-domain sustainability scores

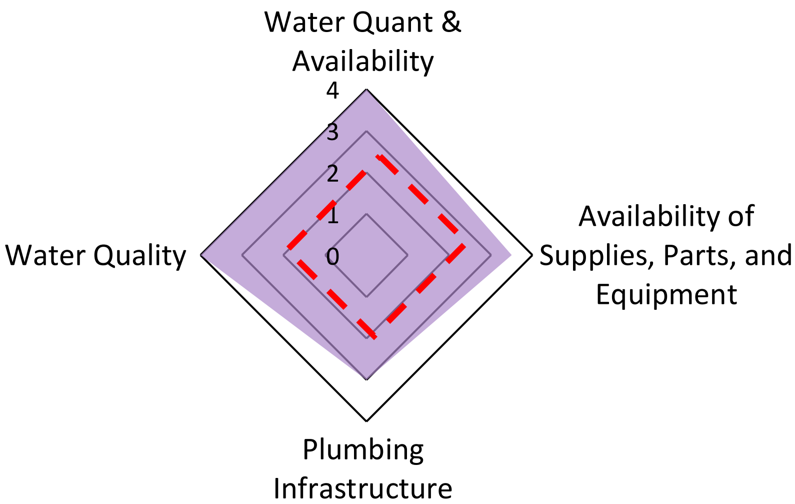


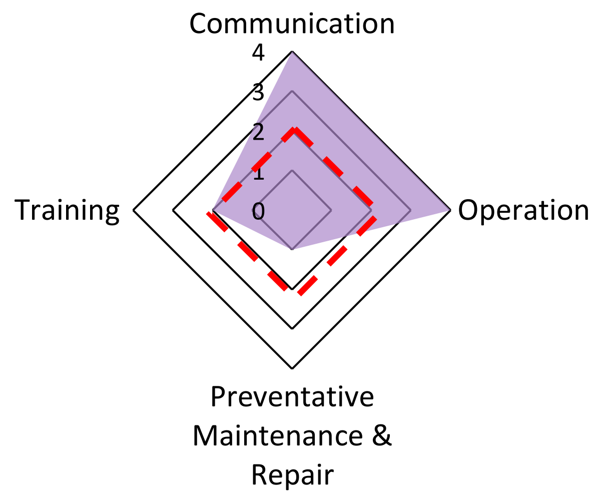


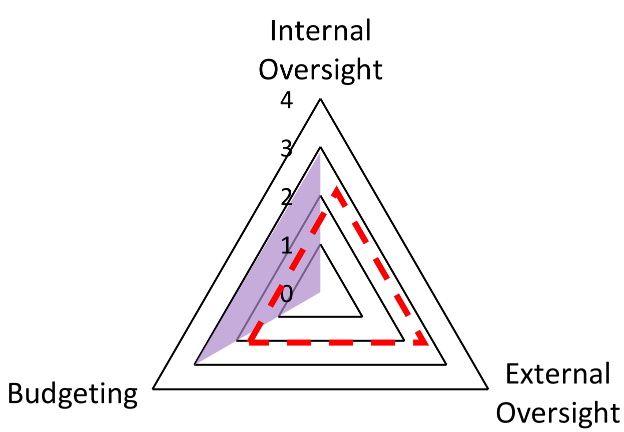


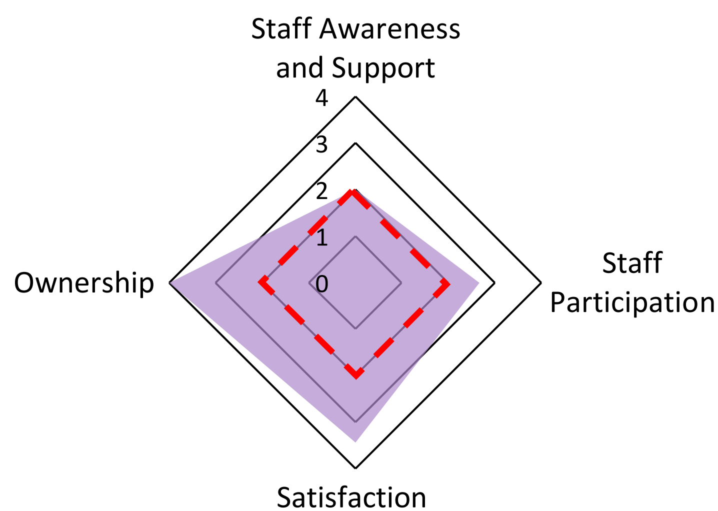


4p. Oudongk 2017 Sub-domain sustainability scores

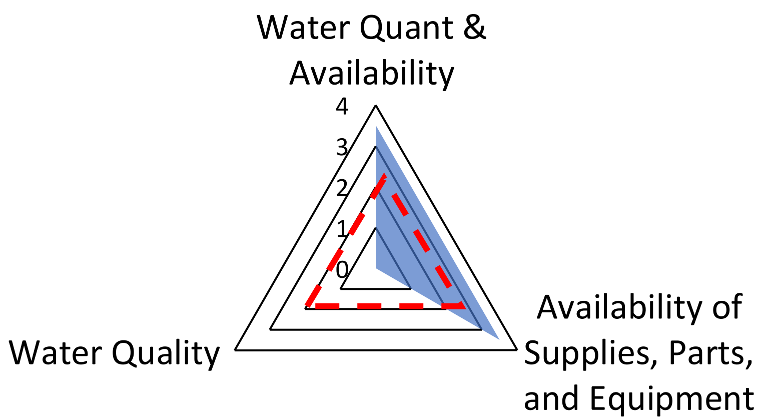


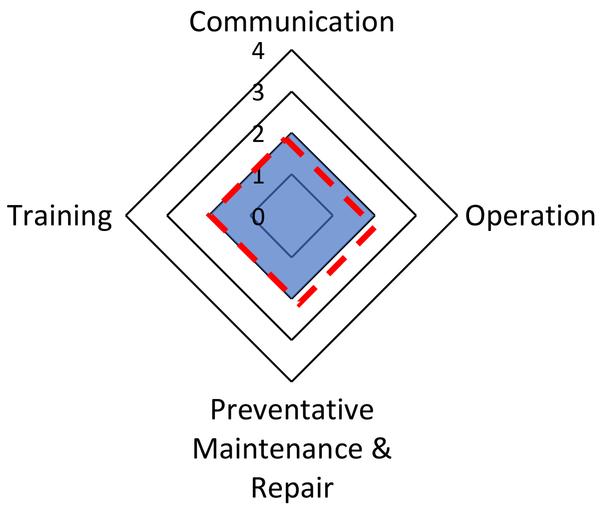


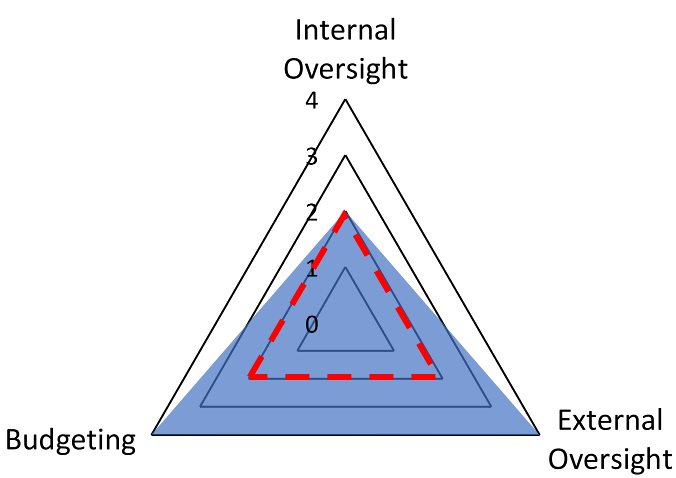


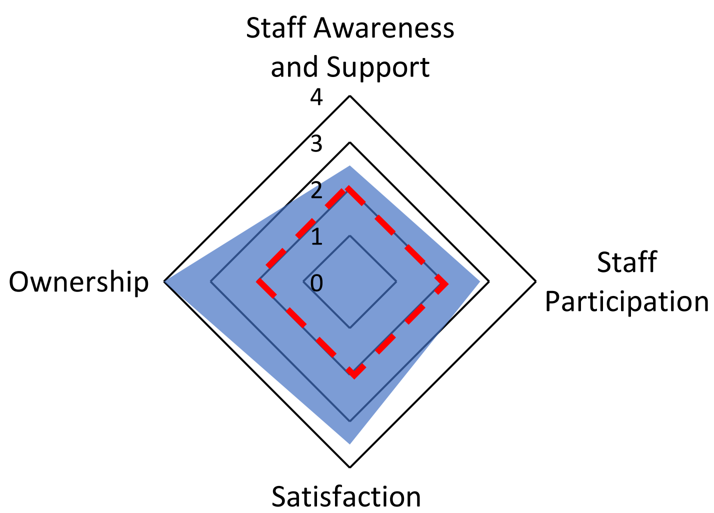


4q. Oudongk 2019 Sub-domain sustainability scores

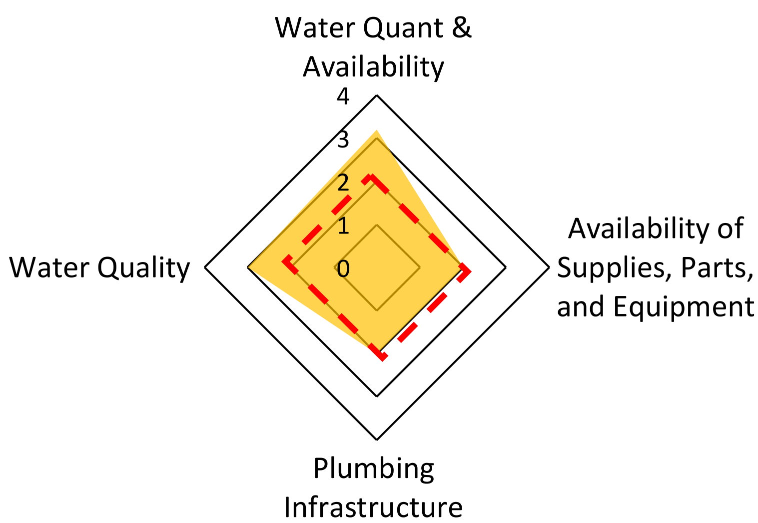


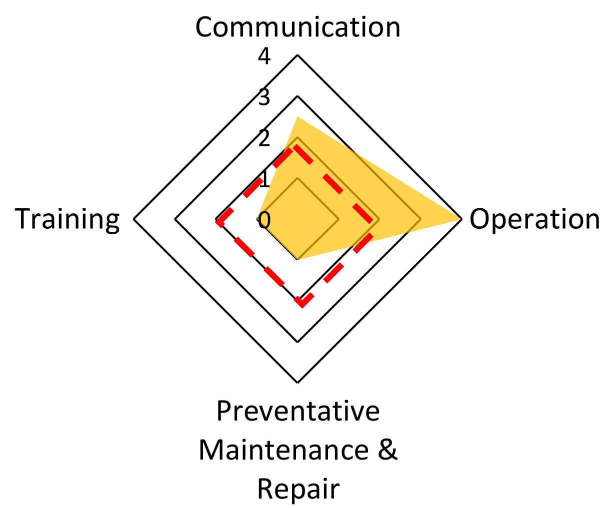


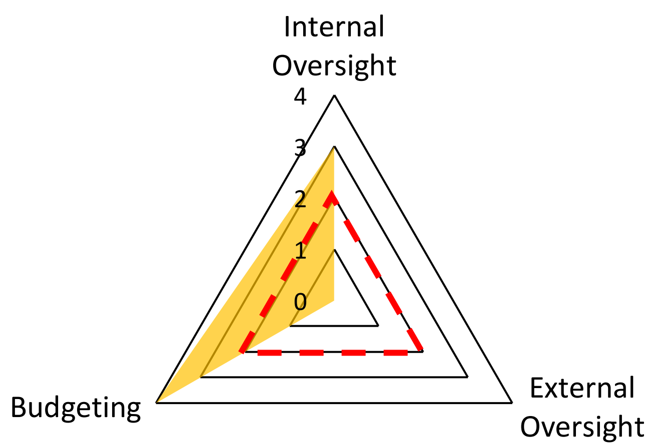


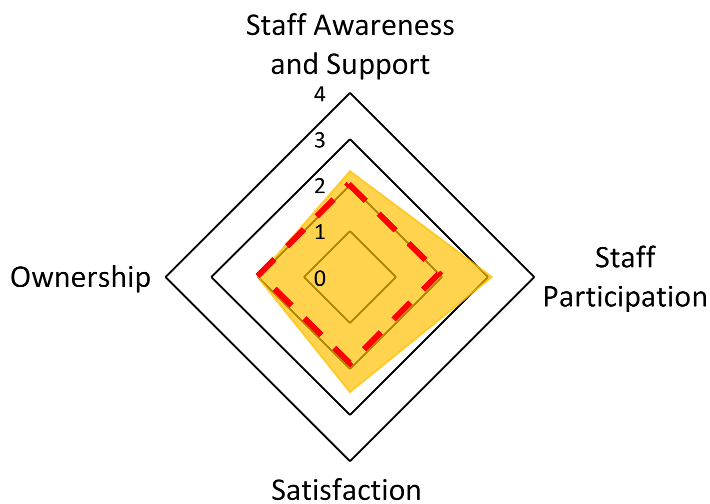


4r. Sampov Lun 2015/2016 Sub-domain sustainability scores

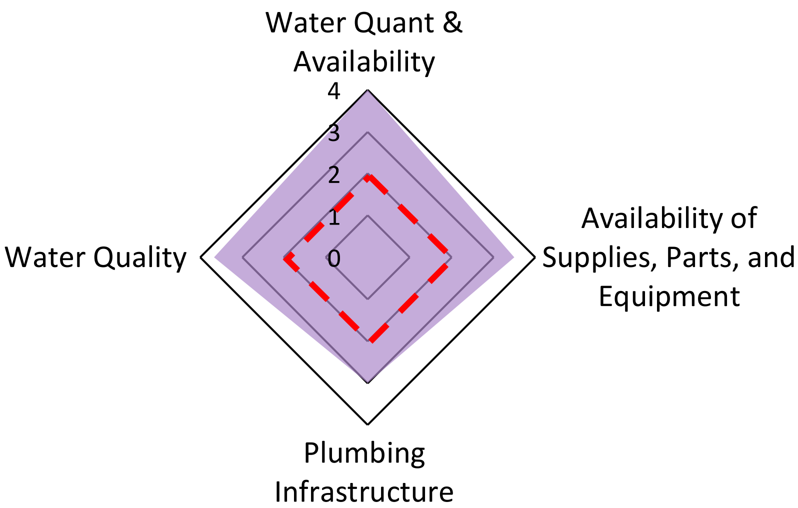


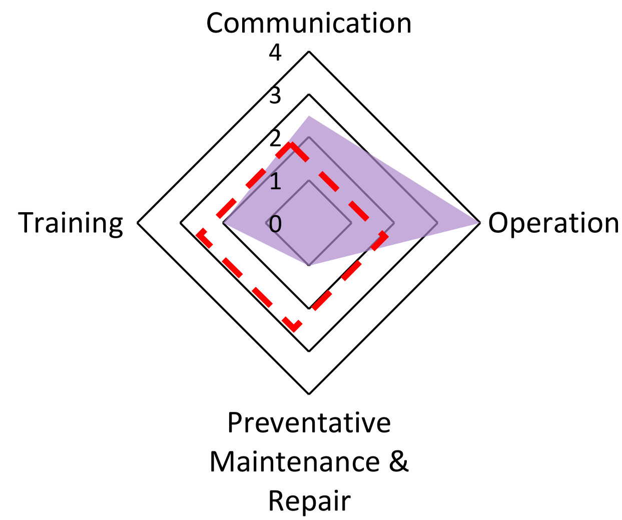


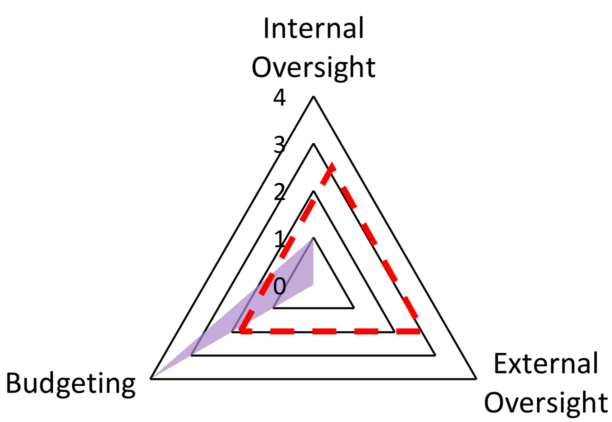


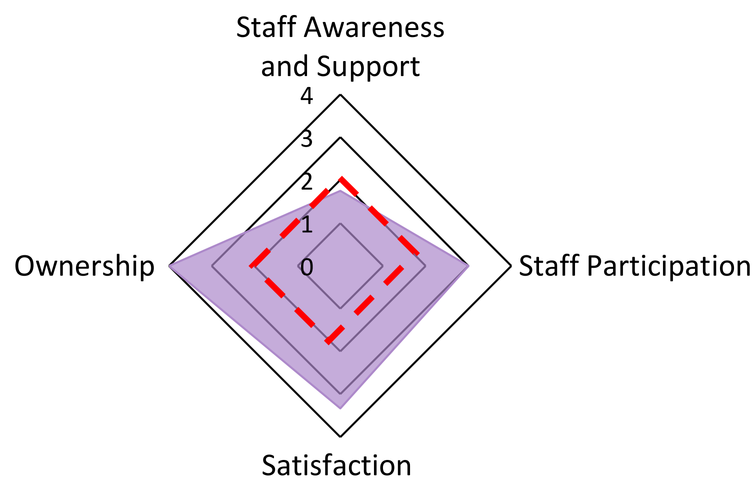


4s. Sampov Lun 2017 Sub-domain sustainability scores









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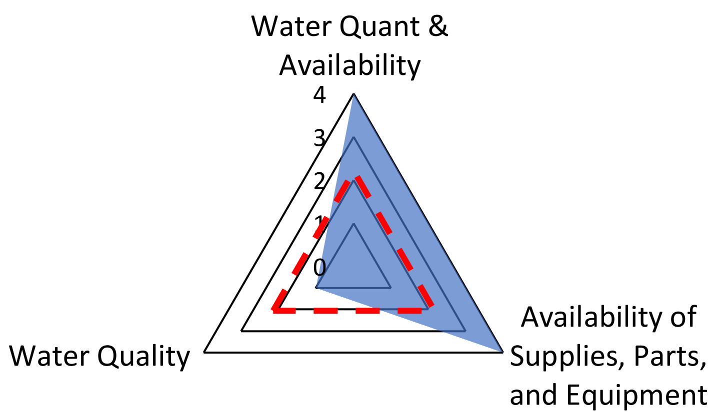
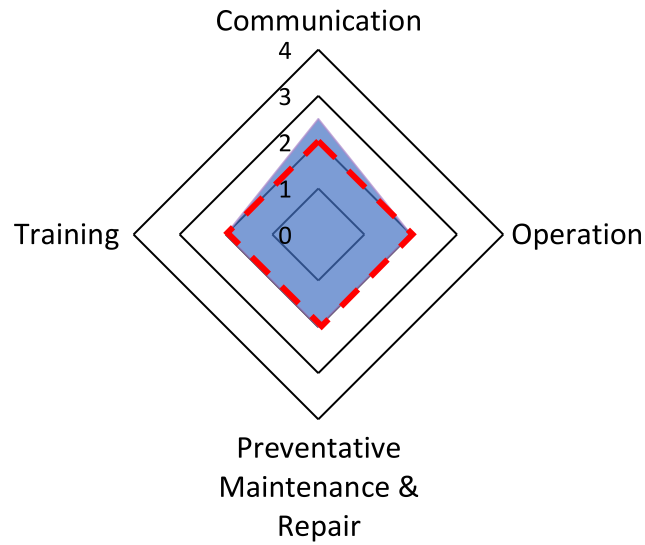
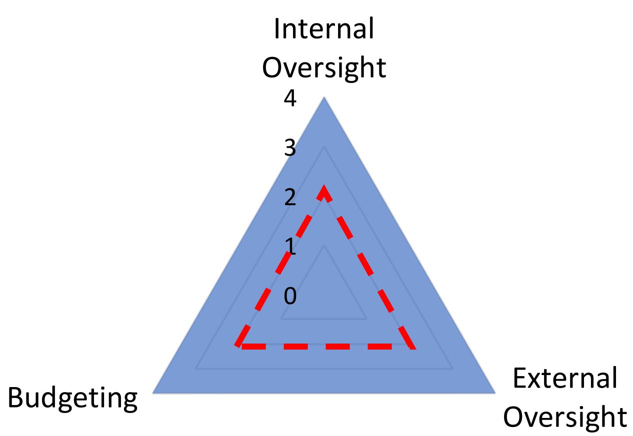
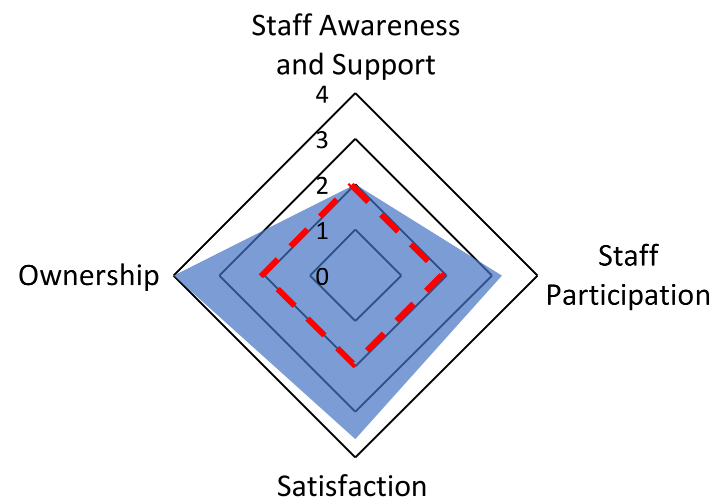
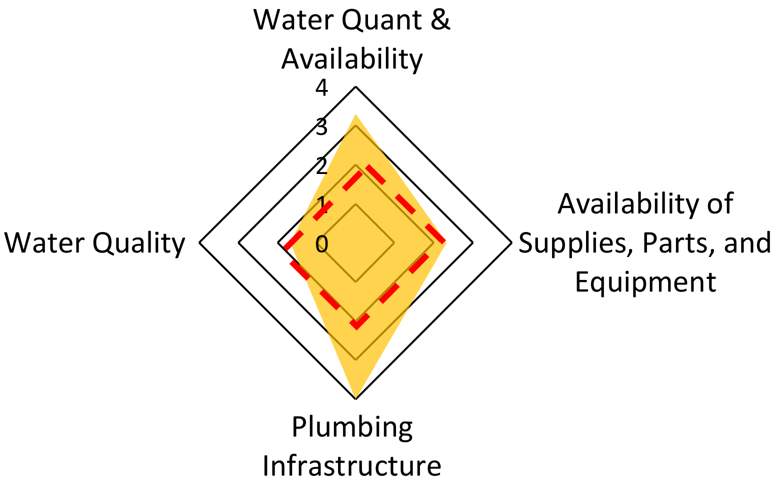


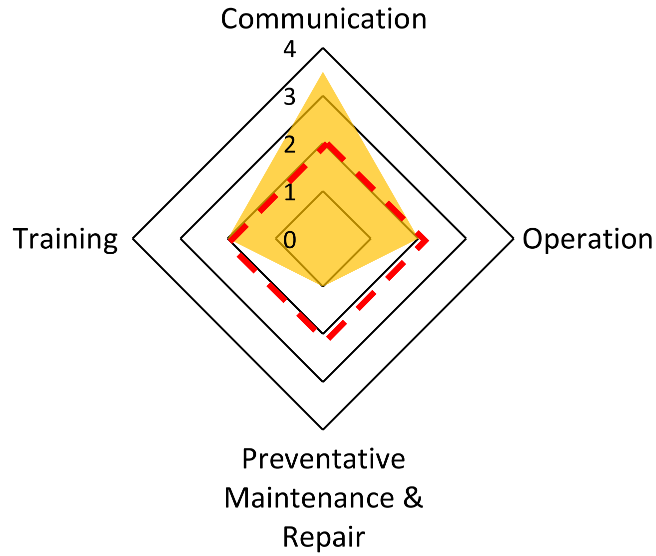


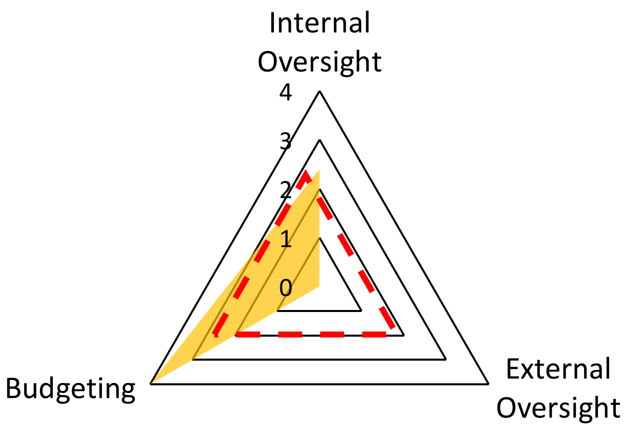


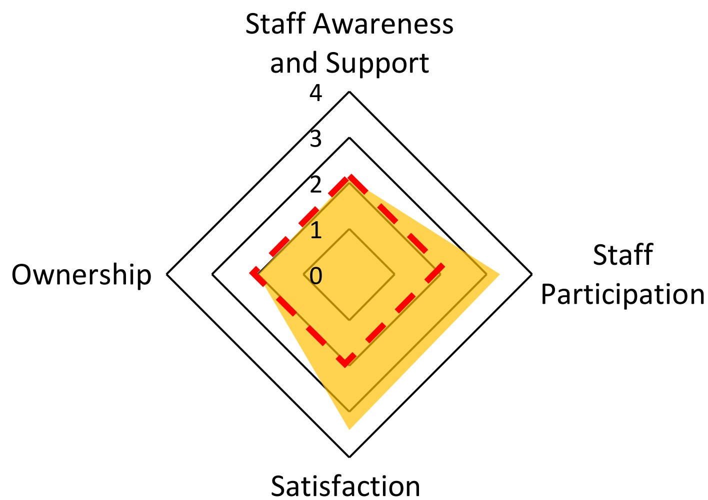


4u. Thmar Kol 2015/2016 Sub-domain sustainability scores









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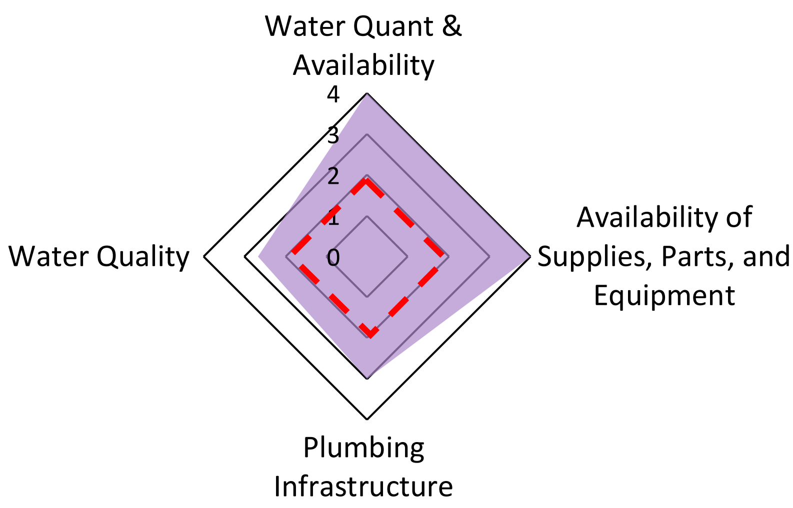
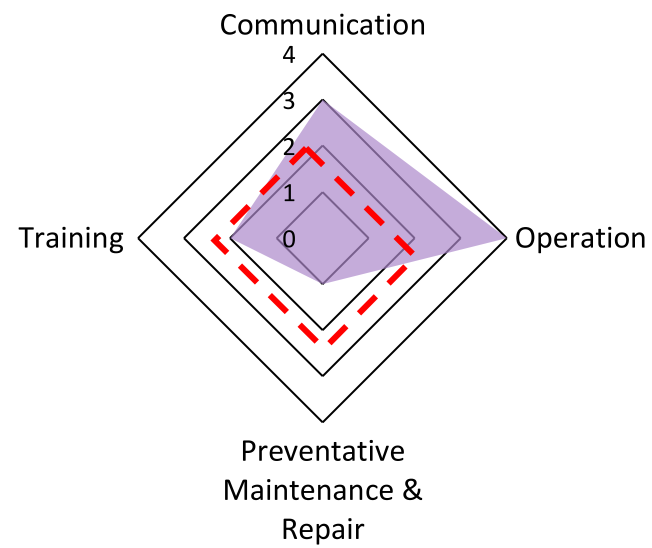
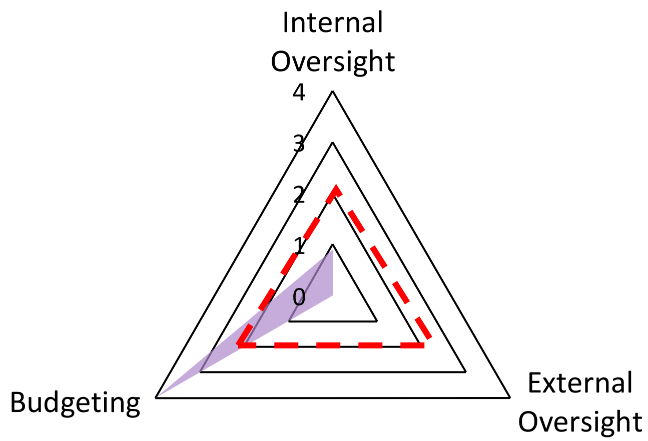
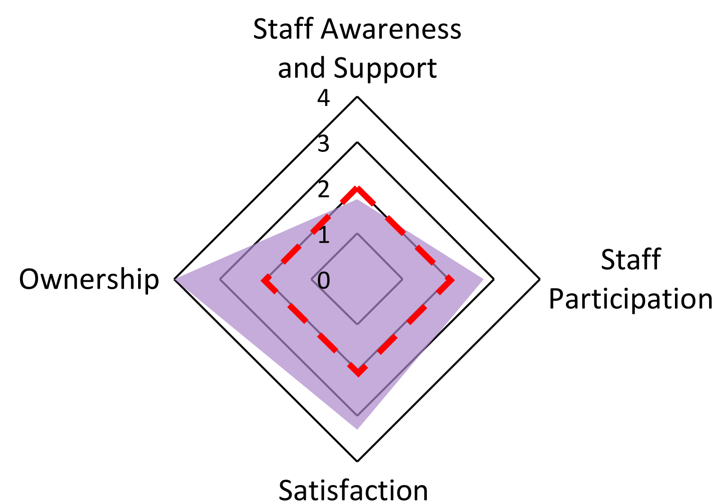
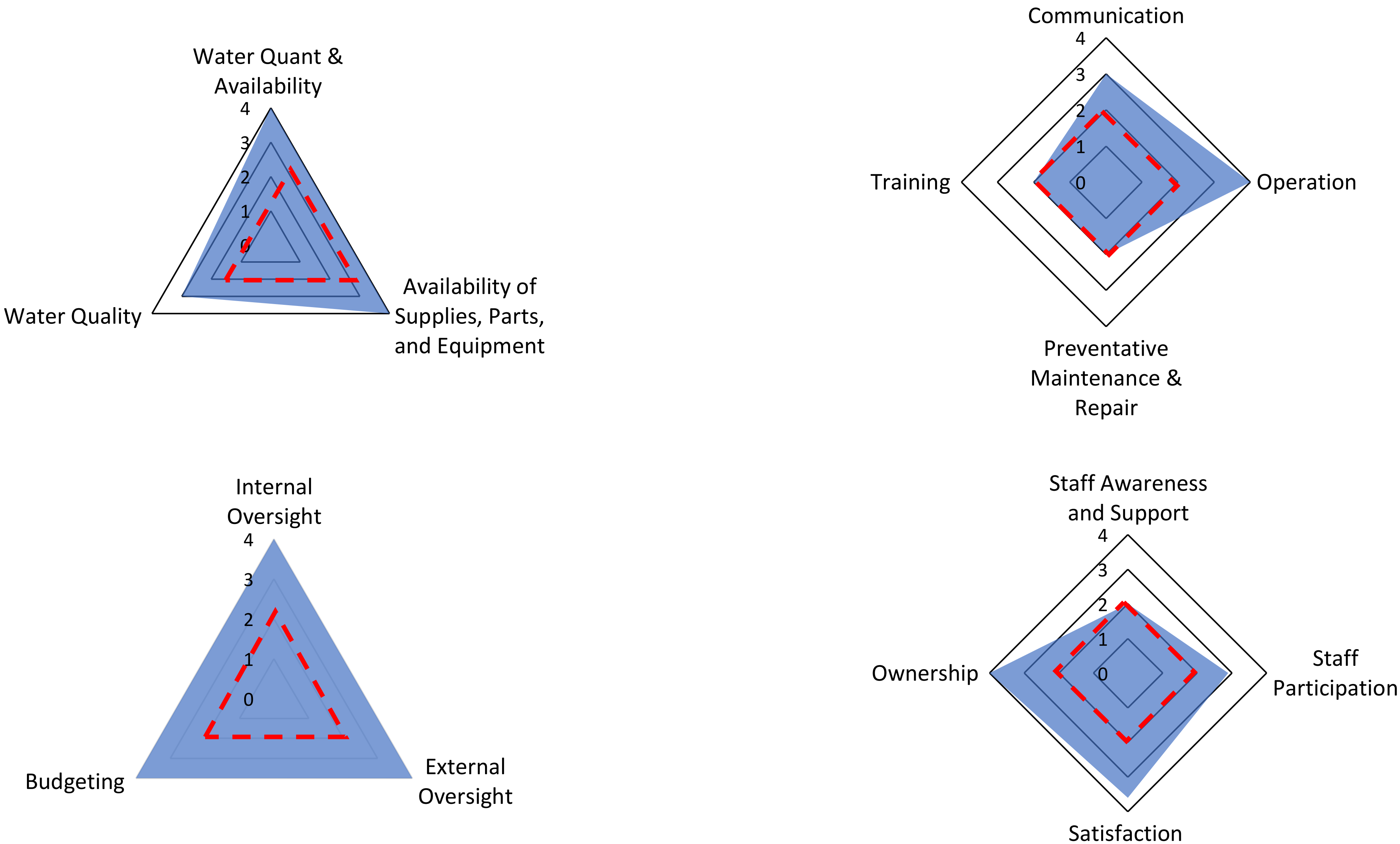




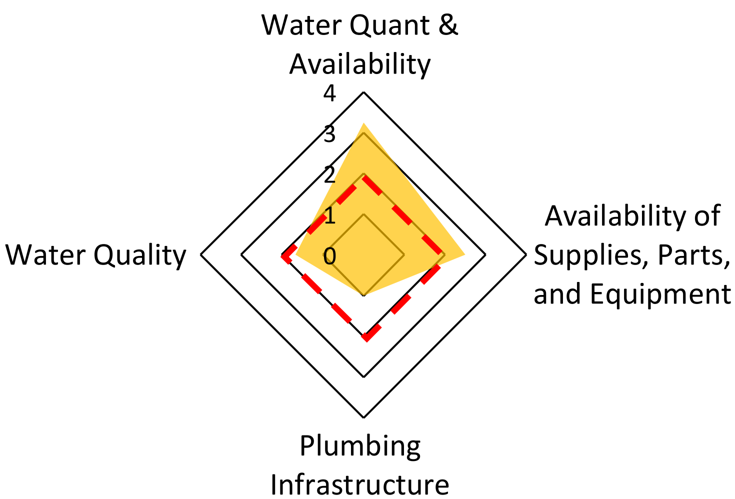


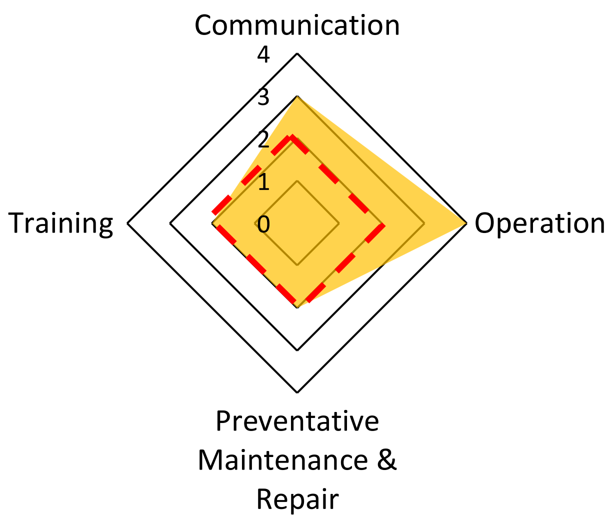


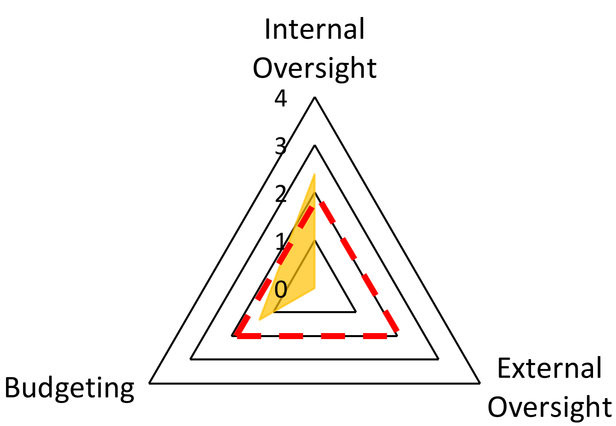
4w. Thmar Kol 2019 Sub-domain sustainability scores

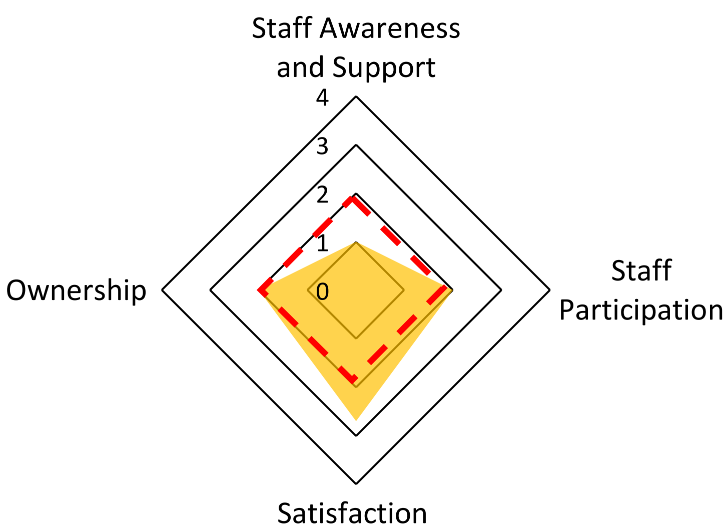


4x. Bun Rany Hun Sen 2015/2016 Sub-domain sustainability scores









4y. Bun Rany Hun Sen 2019 Sub-domain sustainability scores