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Availability and Treatment Efficacy of On-Site Household Sanitation Systems in Indonesia: Mixed Methods Analysis

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Mixed Methods Analysis

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B.S.
The Ohio State University
2014

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Abstract

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INTRODUCTION: Adequate sanitation remains an unattainable need for billions around the world. Past and present development programs aim to reduce those without access, and well-performing and appropriate solutions are essential to addressing these needs. Indonesia is a country with countrywide sanitation access at over 60%, where many low-income communities living in dense urban or challenging environments remain underserved. This study addresses 3 aims: (1) document alternative sanitation system designs and principles through literature reviews, stakeholder interviews, and observations, (2) determine stakeholder-recommended on-site sanitation systems and technologies, (3) analyze treatment levels of alternative on-site sanitation systems.

METHODS: Data was collected utilizing literature reviews, stakeholder interviews, household surveys, system observations, and laboratory analysis. Literature reviews and interviews were used to determine availability and design factors associated with alternative sanitation systems throughout Indonesia, including locations, recommendations, and technical factors. These data were analyzed to determine common themes of stakeholder recommendations and to aid in later field studies. Surveys and observations were performed at households utilizing alternative on-site sanitation systems and are used to analyze design and operational factors alongside effluent. Laboratory analysis was performed using wastewater effluent collected during field studies. This data was analyzed to determine differential treatment levels and influential factors for varying designs. Multivariate ridge regression was utilized to evaluate treatment indicators by potential predictor variables impacted by multicollinearity, such as design factors, operational factors, and other quality indicators. Primary outcome indicators include pH, biochemical oxygen demand, chemical oxygen demand, total suspended solids, oils and grease, *Escherichia coli*, and fecal sludge depth.

FINDINGS: Literature reviews and stakeholder interviews identified 10 on-site sanitation system designs, condensed into 9 categories based on common designs. Themes related to nutrients, fecal indicators, fecal sludge, and the design of systems were common across stakeholders interviewed, and were reflected in many of the designs seen during field investigations. Through multivariate ridge regression, system volume, number of filters, and type of inflow were found to predict multiple treatment indicators. In regards to operational and environmental factors, number of household members, emptying/desludging frequency, years in household, age of system, and temperature were found to predict multiple treatment indicators.

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BACKGROUND

According to the United Nations (UN), 2.4 billion people currently lack access to improved sanitation throughout the world (United Nations, 2015). The distribution of those lacking access highlights an important factor in both international development and human rights: inequality. The majority of those lacking access to sanitation reside in low- and middle-income countries (LMICs), and the differential coverage is typically most pronounced when comparisons are made across the wealth quintiles (WHO and UNICEF, 2015a). Previous international development campaigns sought to address this issue, the most notable of which being the Millennium Development Goals (MDGs) era that occurred from 2000-2015. Through this campaign and ongoing work, 2.1 billion people gained access to improved sanitation since 1990. Even so, the progress realized did not meet the proposed target for the close of the UN initiative, and more ambitious targets were adopted by the international development community in 2015 (United Nations, 2015; United Nations, 2015a). The current target under the Sustainable Development Goals (SDGs) proposes to, 'by 2030, achieve universal access to adequate and equitable sanitation and hygiene for all, and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations' (WHO and UNICEF, 2015).

An important human rights issue surrounding sanitation is the inequitable coverage in access to improved sanitation. Inequalities between the rich and poor can be quite pronounced, and tend to be most alarming in LMICs. Some countries have shown over 80% difference in sanitation coverage between the highest income quintile and the lowest. For example, in Sub-Saharan Africa, the richest have 91% access and the poorest 42%, and in South Asia, the gap is even larger, with 94% of the richest and only 7% of the poorest having access, compared to total coverage of 67%(Blackett *et al.,* 2013, WHO and UNICEF, 2015a).

A critical feature to consider is the current data monitoring methods, which tend to underestimate the disparities between the low- and high-income communities and households. High-income areas tend to be emphasized in the access figures simply due to the household survey and census practices in many countries, reducing the data available for low-income urban areas and unregistered slums (WHO and UNICEF, 2015). While incomplete sanitation coverage is an important human rights issue, it also leads to health and environmental impacts that move beyond individual rights to community-level rights (Root, 2001).

An important hurdle in solving sanitation issues is that infrastructure coverage alone is not enough; quality and sustainability of both infrastructure and services are equally important aspects to be considered (Montgomery *et al.,* 2009; Ziegelbauer *et al.,* 2012, WHO and UNICEF, 2015). Sanitation is private matter with community-wide impacts, and this attribute poses great difficulty in finding and solving issues. Sanitation is an important barrier to prevent transmission of harmful bacteria, viruses, protozoa, and other fecal-related pathogens and environmental hazards (Jha *et al.,* 2012). Sanitation may be especially important in highly traversed urban areas, areas prone to flooding, areas near waterways, and other environments that promote transfer of excrement (Colombara, 2013, Graham and Polizzotto, 2013).

Worldwide, as of 2015, 82% of urban households and 51% of rural households had access to improved sanitation, as reported by the Joint Monitoring Programme on Water and Sanitation (WHO and UNICEF, 2015a). According to the UN, the global population residing in urban areas surpassed that of rural areas in 2009, and the gap is expected to grow by 2.5 billion, exceeding 6.3 billion between 2014 and 2050. Considering where the majority of urbanization is expected to occur, LMICs and low-income countries stand out, where populations are expected to be 57% and 48% urban, respectively, by 2050 (United Nations, 2015). Already, urbanization is impacting the state of sanitation throughout the world. From 1990-2015, urbanization outpaced increases in sanitation coverage in South-Eastern Asia, Southern Asia, Oceania, and Sub-Saharan Africa. This resulted in an increase in those unable to access improved sanitation in urban areas by 35%, bringing the total population to 684 million (Blackett *et al.,* 2013). Regardless of location, the definition of improved sanitation needs to be considered to interpret the coverage levels and assess the current situation of sanitation around the world.

During the MDG monitoring era, WHO and UNICEF define an improved sanitation system as "one that hygienically separates human excreta from human contact" (WHO and UNICEF, 2015a). An important condition is that sanitation in this sense does not only relate to the system infrastructure itself, but rather the entirety of the sanitation service chain, seen in Figure 1. The sanitation service chain, sometimes referred to as the sanitation value chain, is a way of representing all aspects of sanitation from defecation to the final reuse and disposal of excreta. Each step highlights an area in which any break in service could be harmful to human and environmental health.

Figure 1. Sanitation Service Chain

The global community recognized the need to evaluate the entire sanitation service chain, and this interest led to many studies showing how cities handle both individual aspects and the holistic chain. One study by the World Bank looked at fecal sludge management in 12 cities around the globe, and the results showed an alarming trend (Blackett *et al.*, 2014). Cities that had high sanitation coverage (either improved or unimproved) did not tend to fare any better than those with poor sanitation coverage when looking at the flow of waste from containment to reuse and disposal. For example, Dakar, Senegal, has improved sanitation coverage estimated to be 65%, yet only 31% of fecal waste is safely contained, emptied, transported, treated, and reused or disposed. Looking at Dhaka, Bangladesh, the figures are even more alarming: urban improved sanitation coverage was estimated to be 58% with only 2% of fecal waste safely managed (Blackett *et al.*, 2014, WHO and UNICEF, 2015a).

In the SDG era, monitoring and evaluation of the comprehensive sanitation service chain will be of increasing importance and similar studies will be used to evaluate international development progress and gaps that need to be addressed. An important point to consider in many developing countries and LMICs is that for many, sewerage and centralized treatment will not be attainable in the near future, as expenses will continue to be out of reach of many sanitation sector budgets. In these situations, on-site sanitation systems with decentralized treatment will be an important intermediate step for some and the primary waste disposal and treatment technology for many others.

On-site sanitation systems are those that combine user interface and containment (Franceys *et al.,* 1992). Typical on-site systems include ventilated improved pit latrines, single/double pit latrines, composting vaults, *fossa alterna*, septic tanks, anaerobic baffled reactors, and others, which are either dry, urine-diverting, pour flush, or cistern flush systems (Tilley *et al.,* 2014). The wide range of technologies allows for the needs of environmentally diverse communities to be met. Dry systems can use time, heat, or other mechanisms to inactivate many pathogens in excreta, ultimately resulting in a composted material safe for reuse as fertilizer or other uses. Wet systems require more infrastructural- and service-intensive treatment technology. These can be part of the system itself, such as septic tanks with leach fields, anaerobic baffled reactors, trickling filters, anaerobic filter units, or other technologies, or there may be small-scale community sewerage or effluent transport to a community decentralized system.

One major element to consider is the need for both treatment of wastewater effluent and in many instances, fecal sludge (Tilley *et al.,* 2014). With most systems that are not designed to be abandoned, moved, or used in alternate with multiple containment mechanisms, adequate and safe emptying, transport, and treatment of wastewater effluent and fecal sludge is important to realize the benefits of improved sanitation. In many urban and other challenging environments, it can be an immense challenge to ensure the safe operation of these systems. Many on-site systems are not designed to provide wastewater and excreta treatment, but are designed to act as containment devices for further treatment by decentralized treatment systems or natural systems, such as leach fields or constructed wetlands. The systems themselves are not expected to provide treatment necessary to meet environmental and public health needs and the wastewater and sludge are expected to have further treatment, either on- or off-site.

An important and growing method of addressing these challenges can be seen in the technological innovation surrounding the field of on-site sanitation. Many new system designs are being developed and providing promising solutions to many communities that might otherwise be unable to reach the level of sanitation coverage called for by the international development community. Although the technological innovation is necessary for the advancement of development in the sanitation sector, it is important to consider the impacts of each system and to evaluate the installation, operation, and performance to ensure they are meeting the needs of the community and the requirements of treatment recommendations and regulations.

This project was conducted to assess the availability and treatment efficacy of on-site sanitation systems throughout Indonesia. Many new systems have been developed and tested in a laboratory or small-scale setting, but little research has been done to assess the performance of these systems in the communities that utilize them as a primary method of wastewater containment and treatment.

SIGNIFICANCE

Sanitation is important for all people, whether rich, poor, urban, or rural, and has many important implications on the health of a society. When assessing the potential health impact of sanitation interventions, three aspects are of utmost importance: coverage, use, and sustainability, of both infrastructure and services.

Numerous studies have shown the impact of increased sanitation coverage on the reduction soil-transmitted helminth infection and diarrheal disease (Daniels et al., 1990; Esrey et al., 1991; Esrey, 1996; Strunz et al., 2014; Fewtrell et al., 2005; Ziegelbauer et al., 2012). Furthermore, studies have shown the deleterious effects that inadequate use of improved sanitation systems can have on the health of a community (Clasen et al., 2014; Strunz et al., 2014; Montgomery et al., 2010; Wolf et al., 2014; Ziegelbauer et al., 2012). Lastly, insufficient quality of latrines through a lack of operation and maintenance sustainability planning, as well as inadequate wastewater management services, have been shown to have more adverse health outcomes such as diarrheal disease and intestinal parasitic infections when compared to those with more sustainable infrastructure and services (Escamilla et al. 2013; Feachem et al., 1983; Corrales et al., 2006; Moraes et al., 2004; Moraes & Cairncross, 2004; Shuval, 2003). These health impacts are seen throughout Indonesia due to the state of sanitation, as well as other facets of society.

Due to inadequate sanitation and poor hygiene, over 6.3 billion US dollars are lost each year (World Bank, 2013a). This is equivalent to 2.3 percent of Indonesia's gross domestic product and has important implications on development and progress throughout the country (World Bank, 2013a). Moreover, over 50,000 deaths occur each year that are attributed to poor sanitation and hygiene (WSP, 2008). Childhood stunting is another health impact associated with inadequate sanitation, and throughout Indonesia, the prevalence of childhood stunting in those less than 5 years of age is over 36% (Pinto, 2013). These impacts can be felt from any inadequacy along the sanitation service chain, and throughout Indonesia, on-site sanitation is the primary means of containment and primary treatment.

On-site sanitation is a subject with many complex systems and services, and while these complexities are pressing matters for both rural and urban contexts, urban areas and other challenging environments have many specific needs that need to be met. The current trends of urbanization seen globally and in Indonesia, where 138 million residents lived in urban areas in 2015 and over 200 million are expected by 2035, highlight the need for time-sensitive and evidence-based technical recommendations for decentralized, on-site sanitation systems (World Bank, 2013a; Mills *et al.* 2014).

Sanitation in Indonesia

Indonesia, a Southeast Asian country comprised of thousands of islands, is home to over 250 million people. As of 2015, countrywide sanitation coverage was estimated to be 61%, missing the MDG target outlined by the United Nations (WHO and UNICEF, 2015a). Looking at the disaggregation of improved sanitation coverage by urban and rural settings shows that inequality still remains: 72% of urban residents have access compared to 47% of rural. Even greater disparities are seen when looking at access across wealth quintiles for both urban and rural areas (WHO and UNICEF, 2015a). In 2012, those in urban areas as well as the lowest wealth quintile had 47% coverage compared to 96% for the wealthiest, and in rural areas the gap was even larger, with 13% coverage for the poorest and 83% for the richest (WHO and UNICEF, 2015c).

The level of coverage expansion was not enough to meet the MDG target, and pursuit of the SDGs will prove challenging as well due to the population dynamic patterns currently seen in the country. Dense urban areas and other challenging environments such as tidal areas, housing over water, floating communities, flood-prone areas, coastal areas, on-river communities, and many others, require innovative solutions to meet sanitation needs based on environmental factors. Innovative solutions take time to develop and these technologies will be increasingly important with the rate of urbanization and movement into environments necessitating non-standardized sanitation systems. In 2015, 138 million people lived in urban areas and by 2035, that number is expected to grow to over 200 million (Colin *et al.,* 2009, WHO and UNICEF, 2015a). Considering other challenging environments, one study from 2010 found that over 9 million people were living in what they designated as challenging environments. This includes over 2 million people residing on or near rivers and riverbanks, 1.5-2 million people living near or on coastlines, 1.5-2 million people residing in swamps or high groundwater areas, and over 3 million people living in areas with predictable and seasonal flooding (Djonoputro *et al.,* 2010).

The current provision of sanitation throughout Indonesia is that of on-site sanitation systems. 85% of households currently use on-site sanitation systems, primarily septic tanks or lined/unlined pits. 14% of households practice open defecation, and less than 2% have access to and use sewerage-based systems (Mills *et al.,* 2014; Eales *et al.,* 2013; BPS, 2013). For many of the 85% that utilize on-site sanitation systems, an initial classification of 'septic tank' can be a misnomer. One study found that of 178 systems originally considered to be 'septic tanks', 83% were cubluks (unlined pits) and only 8% kept the original classification of septic tank (Mills *et al.,* 2014). Cubluks themselves might be appropriate in some settings, but in many urban areas and challenging environments, they can contribute to environmental contamination and lead to many environmental and health impacts.

Some of this misclassification and differential planning and construction may be due to the current standards in place for on-site sanitation. There is currently only one national standard on-site sanitation system in Indonesia: a septic tank that is built on-site with a leach field (BSN, 2002). Further understanding of the policies, programs, standards, and regulations of sanitation in Indonesia need to be considered to fully understand the issues at hand, and the following sections will advance discussion into the background behind the current situation.

Indonesia Sanitation Policy and Programs

Indonesia has undergone a recent decentralization of the government, as a result of the 1999 constitutional reform, that shifted many roles and responsibilities from the national government to provincial, district, and local governments. This process has led to many opportunities throughout the country but has also presented challenges, many of which in the sanitation sector. Local governments were responsible for providing communities with adequate sanitation, creating and updating sanitation policy, and for monitoring, evaluating, and enforcing regulations. These changes took place with little oversight, which led to gaps in the understanding and capacity to handle the newly recognized roles and responsibilities of the more localized governments (World Bank, 2013). Even with these challenges, the Government of Indonesia has shown great commitment to advancing the state of sanitation throughout the country.

From 2006 through 2010, the government's Indonesia Sanitation Sector Development Program (ISSDP) furthered government commitment to and action towards advancing sanitation throughout the country. Overall, 12 cities had developed city-wide sanitation strategies that planned progress towards increased sanitation coverage and began working to achieve the proposed goals. Government funding had increased, further program scale-up was approved, and 300 cities were contracted to expand the ISSDP (Colin, 2011). By 2012, national funding for sanitation had increased over 900% since 2006, reaching over 400 million USD that year alone (World Bank, 2013).

The current focus of sanitation programs centers around community-managed anaerobic decentralized wastewater treatment systems, or DEWATS. The bulk of national funding has gone towards implementing these systems, and in 2009 the government proposed to expand DEWATS service to reach 5% of the urban population, or 6 million people, by 2014 (Eales *et al.,* 2013). Other programs included the IUWASH program, or Indonesia Urban Water, Sanitation, and Hygiene program, supported by a partnership between the Government of Indonesia and USAID. The main focus of this program was urban sanitation, and primarily pursued increasing both access to and use of safe water and sanitation infrastructure (IUWASH, 2015). These two programs are ongoing in various aspects, and the current development progress is being made following the Presidential Decree of 2014.

The President of Indonesia, Joko Widodo, enacted a decree/regulation that outlined the "acceleration of drinking water supply and sanitation" called Presidential Decree/Regulation no. 185 (Widodo, 2014). This decree provided requirements pertaining to technology, principles of sanitation expansion, and "roadmaps" for future WASH interventions. Governments were required to both develop and implement what they term "effective and efficient" sanitation technology, paying special attention to sustainability, equity, environmental consciousness, and conservation/protection of water resources (Widodo, 2014). This decree provided the backbone for the Medium Term Development Plan which explicitly stated the goal of reaching universal sanitation by 2019, well ahead of the SDG sanitation goals (IUWASH, 2015; WSP, 2015). The two main sanitation aims of this plan align with the SDG targets, both ensuring universal access as well as safely managed sanitation services resulting in adequate treatment and disposal of fecal sludge (WSP, 2015). These national policies and programs set the stage for local government action in accordance with activities laid out in sanitation related laws.

Decentralization laws enacted in 2004 provide guidance and set the structure of local government responsibilities and action regarding sanitation. Law 32/2004 states that regional governments by districts and provinces are responsible for developing and enacting policy, providing sanitation, and developing and enforcing regulations and technological standards.

Another law, Law 33/2004, laid out the financial transfer process for sanitation sector development along with the decentralization of investment, putting much of the burden on local governments.

The end result was that many different stakeholders were involved in the sanitation sector, from national government, to local government, to the private sector. The National Government of Indonesia is responsible for setting standards for on-site sanitation systems, in terms of infrastructure design, construction, and performance parameters. Local governments have the option of setting alternative standards; given that they fall within those of the national government. The responsibility for enforcing these standards and regulations falls on the local government, which may lack the capacity or financial requirements to adequately do so (World Bank, 2013a).

SANITATION REGULATIONS AND STANDARDS

Indonesia currently has one national standard on-site sanitation system design. This design outlines the construction and implementation requirements for a septic tank that is built on site with a leach field, seen in Figure 2. The minimum volume set forth is 2.1 m^3 in addition to a leach field for effluent discharge. The document from the National Standardization Agency (BSN) also describes an optional 'tangki septik modifikasi', or modified septic tank (Figure

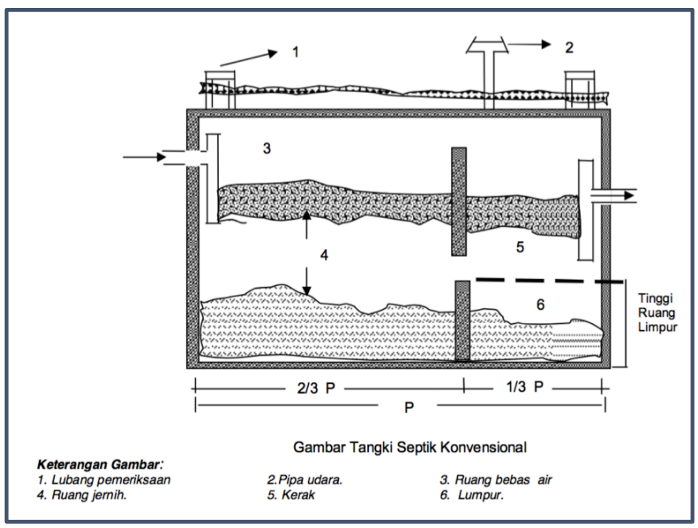


Figure 2. National Standard Modified Septic Tank, SNI 03-2398-2002 (BSN, 2002)

3), as well as a spherical tank with a volume of 1.7m^3. The modified and spherical tanks still required leach fields for effluent discharge, and may be prefabricated or built on-site (BSN, 2002).

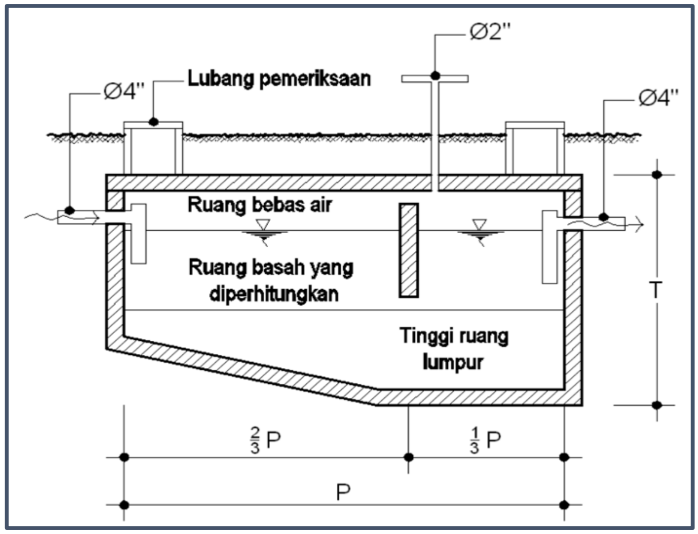


Figure 3. National Standard Septic Tank, SNI 03-2398-2002 (BSN, 2002)

The standard design seen in Figure 2 is similar to that of international septic tank design recommendations, and would be an appropriate on-site sanitation system for those living in environments that support the construction and operation requirements. The issue with this design lies in the fact that, as noted above, over 9 million Indonesians live in challenging environments and currently over 138 million people live in urban areas (Djonoputro *et al.,* 2010; WHO and UNICEF, 2015a). In many of these areas, it is unfeasible or potentially harmful to utilize leach fields, as they may contaminate groundwater, surface water, or the broader environment due to various conditions. Available space also becomes an issue when considering the needed volume, and many dense urban areas cannot support the septic tank as designed. Considering the modified and spherical designs, little has been done to assess their functioning when implemented and some aspects go against recommended septic tank designs, such as the slope of the tank and the design of the baffle.

Wastewater effluent standards are also set by the national government and can be seen in Table 1 (MENLHK, 2016). These are the requirements to be met by sanitation systems as the wastewater effluent is entering the environment. Local governments may choose to set alternative standards as they see fit, as long as they fit within the standards set by the national government (World Bank, 2013a).

Table 1. Wastewater Effluent Quality Standards, Ministry of Environment and Forestry Regulation No. 68/2016

Parameter	Maximum Level	Units
pH	6-9	-
BOD (biochemical oxygen demand)	30	mg/L
COD (chemical oxygen demand)	100	mg/L
TSS (total suspended solids)	30	mg/L
OG (oils and grease/fat)	5	mg/L
Ammonia	10	mg/L
Total Coliform	3000	cfu/100mL
Discharge	100	liters/person/day

While there are national standards for both construction and treatment performance of septic tanks, there are no regulations on the number allowed per unit of area, no regulation of emptying and maintenance, and, in most cases, no monitoring of construction, operation, maintenance, or performance (BAPPENAS, 2007). All of these are important aspects of sanitation in general, and need to be considered to evaluate the ability of a sanitation system to meet the needs of the community and the requirements of the national and local governments. As seen in Table 2, many of the wastewater effluent quality indicators included in the Ministry of Environment and Forestry's regulations, as well as others, have wide-ranged ramifications in terms of environmental and public health, and monitoring system performance may help ensure systems are functioning at a level that protects human and environmental health.

Table 2. Wastewater Effluent Quality Indicators and their Importance

Indicator	Importance
E. coli and TC	*E. coli* and total coliforms are commonly used indicators of fecal contamination. *E. coli* can be used as an indicator for specific bacterial pathogens, such as *Campylobacter jejuni*, but may not be appropriate for other pathogens such as viruses, protozoa, or other parasites. Their proposed use in this study is to aid in the estimation of the level of fecal matter present in the effluent as well as to test for the presence and level of contamination seen in shallow well water. The presence of these indicator bacteria in effluent or well water indicate potential risk of adverse health outcomes for those who come in contact with the contaminated water, although some studies have found weak correlations between the presence of *E. coli*/TC and risk of diarrheal disease. As with all indicators, each has its limitations although for the scope of the study, the proposed time-frame, and available resources, we conclude that the use of these indicators is the most appropriate and effective choice for measuring performance (Gruber *et al.,* 2014; Ashbolt *et al.,* 2001; WHO, 2011).
BOD	Biological oxygen demand (BOD) is a commonly used indicator of the oxygen demand by microorganisms involved in the degradation of organic material within wastewater treatment systems. The BOD_5 procedure used in this analysis is a measurement of the amount of oxygen consumed by microorganisms in the degradation of organic material over a 5-day period. This measurement is essentially a gauge of the strength of the effluent, as samples with high BOD contain many microorganisms that can deplete the oxygen resources in receiving bodies of water and lead to death of other organisms in the ecosystem (EPA, 2001).
TSS	Total suspended solids (TSS) is used to determine the efficacy of settling chambers and microorganisms in breaking down and settling both organic and inorganic solids. High TSS levels in effluent samples provide implications into the settling efficiency of the tank and potential disturbances in the fecal sludge layer due to shock loads to the system. High levels of TSS in effluent can also indicate potential contamination due to suspended fecal matter or other harmful solids (APHA, 1997).
pH	pH is an important indicator of septic tank functioning as it has an effect on the survival of microorganisms responsible for the digestion of sludge. The optimal values are between 6.5-7.5 and these coincide with the national standards for effluent quality of 6-9 (Ministry of Environment Regulation 68/2016). Studies have also shown that pH levels influence pathogen removal when using porous media or media filters, and these design factors are seen in many of the alternative sanitation systems included in the study (Stevik *et al.,* 2004).
Chlorine	Chlorine will be measured primarily to determine if there will be any interference with *E. coli* or TC concentrations due to disinfection by free chlorine.
Detergents	Detergents in wastewater effluent are an indicator of the introduction of grey water containing soaps and other household cleaning products into the sanitation system. Detergents present in the effluent can have detrimental effects on the environment, as they increase the BOD and can cause harmful algal blooms due to increased phosphate availability in the environment. This can impact drinking water and water used for other household tasks, and is an important factor to investigate the performance of the alternative systems (EPA, 2004).
Fats/Oils	Fats and oils are substances that have the potential to harm both the individual sanitation system as well as community water sources. These substances can bind to walls of the system or pipes and cause decreased treatment efficiency as well as blocked inflow or outflow pipes, leading to overflows and flooding. These substances can have negative effects on other bodies of water and water systems, including wells, sewers, or other piped water sources. Determining the amount in the effluent as well as in the shallow well water can help assess the potential for blockages or disruptions in treatment for both the system and water source (Husain *et al.,* 2014).
Temperature	Temperature has varied effects, both on pathogen reduction as well as sludge accumulation. Generally speaking, increases in temperature result in decreases of

	pathogen loads as well as sludge accumulation, so temperature will be an important factor to consider in this study while assessing the performance and will have effects on the sludge accumulation measurements and chemical analysis (Carrington, 2001).
Sludge Settling	Sludge settling is a measure of the ability of a mixed solution of sludge and water to separate into separate layers in an Imhoff cone or cylindrical beaker. Sludge settling tests will provide indications of settleability, which is relevant to solids retention and sludge accumulation in sanitation systems (Strande *et al.,* 2014).

Study Aims

This study sought to provide empirical evidence on the availability, design, and performance of on-site sanitation systems in Indonesia to help guide technical recommendations for these and other systems. Little is known about alternative on-site sanitation systems in Indonesia, both in terms of availability and performance, and evaluations of their availability and functioning could help address some of these issues. Understanding how current systems are operating on a household level and examining their design and performance will allow for well-informed alternative recommendations to be made and for national sanitation standards to be better suited to urban and challenging environments. These recommendations may contribute to appropriately progressing towards the Government of Indonesia's plan to reach universal sanitation access by 2019 (IUWASH, 2015; WSP, 2015).

The specific aims of this study are to: (1) review existing standards, designs, and key principles of small, prefabricated on-site sanitation systems used by governments and local agencies/organizations in Indonesia, and (2), assess the construction and effluent quality of alternative on-site sanitation systems currently in use, specifically the impact that design modifications have on the treatment of wastewater and their performance compared to the design assumptions.

Materials and Methods

Figure 4. Study Sites - Indonesian Provinces (Tableau Desktop 10.1.1, 2016)

STUDY SITE

This study was conducted throughout the country of Indonesia, mainly focused in the provinces of North Sumatra, DKI Jakarta, Banten, and West Java (Figure 4). Interviews, stakeholder discussions, surveys, and sample collections took place primarily in the proximity of three main cities: Jakarta, Bandung, and Medan.

Table 3 shows the basic geographic, demographic, and sanitation characteristics of the three cities, using data from 2014 (BPS, 2014). The chosen cities represent varying characteristics of challenging environments, with being dense, urban areas, tidal areas, housing over waters, coastal areas, flood-prone areas, areas of high groundwater, and other aspects. Figures 5, 6, and 7 show on-site sanitation system sampling locations across the three main cities. The study sites were not chosen based on these characteristics, but rather the availability and accessibility of the on-site sanitation systems included in this study. Many of the communities included in the study relied primarily on septic tanks as a primary means of waste disposal, although the coverage, sustainability, and use of these varied greatly.

Table 3. Study Sites - City Demographics and Characteristics (BPS, 2014)

City	Province	Population	Population Density Mean	Sanitation Coverage Improved (%)	Septic Tank Use* (%)	Households with ≤ $7.2m^2$ per capita (%)
		Area (km2)	Population Density Range	Sanitation Coverage Private* (%)		
Medan	North Sumatra	2,210,624	8,342	67.89	93.99	13.22
		265.00	NA	75.37		
West Jakarta	DKI Jakarta	2,430,410	18,761	89.28	91.79	29.73
		129.54	NA	76.47		
Bandung	West Java	2,470,802	15713	59.43	60.55	10.16
		167.31	3,732 – 39,817	67.92		

* *Based on 2010 provincial census data (BPS, 2014)*

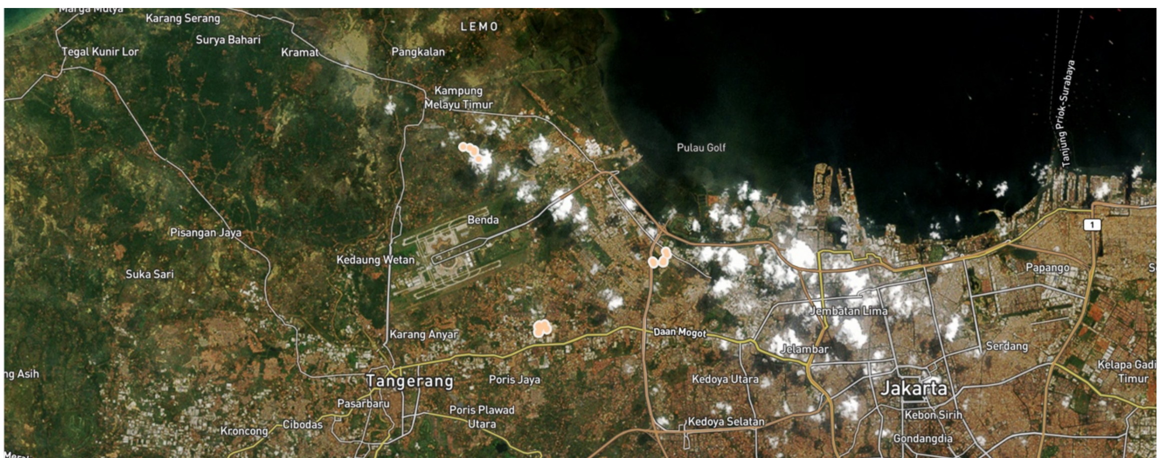


Figure 5. Jakarta Sampling Locations (Tableau Desktop 10.1.1, 2016)

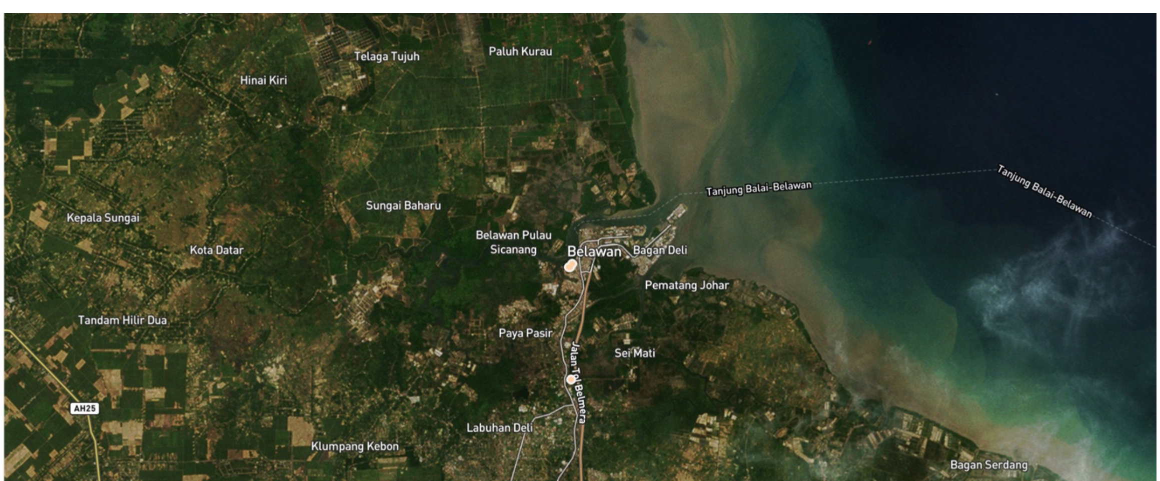


Figure 6. Medan Sampling Locations (Tableau Desktop 10.1.1, 2016)

Figure 7. Bandung Sampling Locations (Tableau Desktop 10.1.1, 2016)

KEY STAKEHOLDER DISCUSSIONS

Prior to the study, a desk review was undertaken to identify key stakeholders, important concepts, and current offerings of alternative sanitation systems throughout Indonesia. Alternative sanitation systems were defined as those that differ from the SNI design, SNI 03-2398-2002 (BSN, 2002)). The result of this review was the identification of key stakeholders at the national and local level, as well as non-governmental entities (Table 4).

Table 4. Indonesian Sanitation Sector Stakeholders (IUWASH, 2015; Kementerian Sekretariat Negara Republik Indonesia, 2010)

Level	Actor	Interest/Involvement
National Government	Ministry of Health	Involved in behavior change, health promotion, and community development in regards to health and the environment. Promotion of sanitation is a large part of the responsibilities of the Ministry of Health
	Ministry of Environment and Forestry	Involved in the regulation of contamination and health of the environment. Involved in the setting of standards for urban sanitation system effluent
	Ministry of Public Works	Provide guidance and support pertaining to development of sanitation in Indonesia. Provide standards and designs of technology options
	Ministry of National Development Planning/ National Development	Involved with community planning and community involvement in reaching the medium term development goals, including the universal sanitation access goal for 2019. Also oversee other

	Planning Agency (BAPPENAS)	departments such as the POKJA AMPL. Implement national development planning program while providing technical assistance to other projects
	Research Center for Housing and Settlements (PUSLITBANGKIM)	One of four institutions under control of the Ministry of Public Works and is involved in studying technology development, housing, and standard development
	National Standardization Agency (BSN)	Set the technical standards for sanitation systems and treatment systems
	National Working Group on Water and Sanitation (POKJA AMPL Nasional)	Managed by BAPPENAS. Members include BAPPENAS, Ministry of Public Works, Ministry of Internal Affairs, Ministry of Health, Ministry of Education and Culture, Ministry of Environment, Ministry of Finance, Central Bureau of Statistics, and other individuals, legislative bodies, and organizations
	Agency for the Assessment and Application of Technology (BPPT)	BPPT is a government institution that is under the control of the Ministry of Research and Technology. Their function is to perform government mandated tasks in respect to implementation and assessment of technology. They provide guidance and recommendations based on the implementation and assessment of technology in regards to sanitation infrastructure
	Urban Sanitation Development Program (USDP)	Technical support project within the PPSP. Provide guidance and technical knowledge to local governments and others within the PPSP
	Association of Sanitary Engineering and Environmental Engineering Indonesia (IATPI)	Involved in voluntary social services related to sanitation as well as national and international seminars and projects. Assists the government in urban environmental planning including aspects of sanitation and waste management
	Mercy Corps	Implement programs related to sanitation and WASH in general throughout Indonesia. Have previous projects in Kalideres, West Jakarta involving new septic tank designs
	IUWASH	Indonesian Urban Water, Sanitation, and Hygiene project funded by USAID. Just finished an assessment pertaining to the the performance of their small sanitation systems being implemented
Local Government	UPTD-PAL (Regional Technical Implementation Unit – Wastewater Management)	Involved with wastewater management at the local government level. In some instances, these units can function as the primary city sanitation management unit, overseeing all aspects of sanitation
	PD-PAL (Local Company – Wastewater Management)	Local government owned and operated company that is similar to UPTD-PAL, but it has a private revenue managing authority and can act independently from its governmental department counterparts

	PDAM (Indonesian Regional Water Utility Company)	Regional public water utility in charge of the provision of water and on occasion for the provision of sanitation as well
	Local Department of Health	Concerned with health of the citizens at the district and city level
Non-Governmental	Private Sector	Involved with provision of sanitation system materials, services, as well as through partnerships with government entities to provide service and technical assistance.
	Foreign Aid/Lenders (World Bank, AUSAID, etc.)	Interested in improving health for the countries involved, and involve the pursuit of the SDG's and support of the Presidential Decree declaring the plan for universal sanitation by 2019
	Community Based Organizations/Community Leaders	Primary interest in improving their communities and others like theirs. Most are made up of citizens and other organizations, and are interested in the welfare of themselves, their neighbors, their community, and people in similar situations in regards to sanitation and other community factors
	City Sanitation Pokja (working groups)	Separate from the POKJA AMPL Nasional, these can be working groups made up of individuals, students, universities, private sector, NGO's, media, and many other groups. These can be at the provincial, district, city, and neighborhood level
	Public Utilities	Interests lie in continuing service and on cost-recovery on investment. They provide service to the community and are mainly interested on seeing a return on investment for sanitation infrastructure and services in urban settings
	Universities/ Research Centers	Interested in developing new technologies to meet the demand of dense urban and challenging environments in relation to on-site sanitation. Also research the design and performance of existing systems presently used throughout Indonesia and the study sites.

National Stakeholder Discussions

Prior to field investigations, stakeholder discussions were performed with select representatives from the stakeholders outlined in Table 4, based on availability. These representatives were expected to be key informants related to on-site sanitation systems and the sanitation sector in general at the national level. The discussions were carried out through small meetings and discussions with individual stakeholders and the aim was to understand the current technological offerings for small alternative on-site sanitation systems in Indonesia. Topics covered current or planned projects to implement alternative systems, gaps or challenges in technological offerings, as well as potential opportunities for improving on-site sanitation in challenging environments that the stakeholders have seen or do see throughout their experiences. Discussions were primarily conducted in Bahasa Indonesia and were recorded with notes taken following translation to English, and in some instances were conducted in English based on the comfort of the stakeholders. Overall, these discussions helped guide the focus of the study onto certain technologies and modifications and assisted in determining study sites. A summary of discussion points includes:

- Current situation of on-site sanitation in Indonesia: What are the standards that apply to these systems? What options are available to households that may not be able to utilize the national standard design (SNI) systems? What policies or regulations are in place?
- Roles of stakeholders in technical development: Who is responsible for promoting sanitation? What initiatives are there for adapting sanitation systems to challenging environments? Who should be responsible for providing alternative systems to those that conventional systems are not feasible?
- Current demand for alternative on-site sanitation systems: Is there a demand for alternative systems from communities living in dense urban or challenging environments? Are there ways in which they can learn about the innovations in terms of modifications or new on-site systems?
- Current supply of alternative on-site sanitation systems: Are technical solutions to the problems faced by conventional sanitation systems being developed to meet the

demand? What are some of the new options for small, on-site sanitation systems for people living in these challenging environments?

- Acceptance and use of alternative systems: Are these new systems being adopted and implemented by local governments and communities to address the problems associated with poor sanitation? Are these systems well received even though they do not meet the SNI standard? Is there oversight into the design and installation of these systems? Are these tested to ensure they meet the effluent quality requirements? What are the standards used in the on-site system upgrading projects (hibah, DAK)? Is there verification or assessment of the design and implementation?

- Thoughts on improvements: What else can be done to meet the demand in these challenging environments where conventional systems are not feasible? Are there other technologies that you feel would be more effective in addressing the problems in these environments?

Study Site Key Stakeholder Discussions

Due to the decentralized nature of the Indonesian government, much of the responsibility for providing sanitation lies in the hands of local governments. Separate stakeholder discussions took place to understand the situation in each specific study site that may differ from those seen through the scope of national organizations. These discussions allowed information pertaining to local standards, regulations, and sanitation options to be obtained that also might not be discovered through national discussions. Representatives from local agencies, such as those listed in Table 4, were invited to participate in discussions pertaining to sanitation systems used in their study site. Stakeholders also provided information on the locations in which the on-site sanitation systems have been installed for the household surveys and technical assessments. A summary of discussion points includes:

- Understanding the study site: How many people live in the city? What are some typical environmental aspects seen there (rivers, bodies of water, dense housing, housing over water, flood areas, high groundwater, tidal areas, etc.)? Are there any informal settlements? Any areas that would be/are challenging for sanitation?
- Sanitation in the study site: Do you think that current sanitation systems are appropriate for this environment? Do they follow guidelines? Is their use/performance as expected? What happens to the waste coming from these systems? What are some examples of innovative systems in place? What services are available for sanitation in this area (sludge removal, operational assistance, maintenance)?
- Technical and policy factors of design and performance: What are some current regulations/policies in place for sanitation system designs and performance? Do these differ from national standards? Are there options for households in different environments? Specific options for dense housing or those in challenging environments?
- Enforcement of design and performance regulations: Who is in charge of enforcing regulations? Are they involved in the planning and installation of systems? Can standards and regulations be altered to meet specific needs on a household-by-household basis? Oversight of planning and installing systems?

- Innovative solutions to sanitation issues: What are some issues your city faces in terms of on-site sanitation systems for housing in challenging environments? Are there technical/political solutions available? How are systems being designed to meet the demand of the environment? What are some alternative systems being used in this area? Are these systems readily available and accessible to communities? Are they affordable? Is there technical assistance available when needed?

Survey Collection

Household surveys were utilized to gather detailed descriptions about the design, performance, and use of the alternative on-site sanitation systems. The households purposefully selected to be surveyed were identified through discussions with local and national level stakeholders as being those with alternative sanitation systems throughout Indonesia. For each study site, households currently using the chosen alternative system were surveyed, with the number of households being surveyed per alternative system design determined by availability and accessibility. The survey data was coupled with the observation and sample data to determine how sanitations systems are functioning in regards to different modifications and technical design aspects.

The focus of the survey was based on four separate sections: general information, socioeconomic/demographic, sanitation information, and technical aspects of sanitation. General information pertained to the characteristics of the household and the survey respondent, such as age, sex, and location. In the socioeconomic/demographic section, questions were more specific in relation to the household and its members. Information such as the housing type, the material, the number of members, employment, water source, and others were gathered through these questions. The sanitation section of the survey focused on aspects of sanitation such as defecation behavior, toilet characteristics, waste disposal, and specific questions about the installation, design, and maintenance needs of the system. The final section dealt with any technical aspects of the system that have been modified and changed in relation to the national SNI standard design. The questions covered topics such as what modifications were made, who performed them, how much did they cost, and why they were made. See Appendix A for the complete survey tool to be used in the study. The survey was created in English and translated and conducted in Bahasa Indonesia.

TECHNICAL ASSESSMENT

The technical assessment aspect of the study allows for evidence-based technical recommendations to be provided as it investigated system functioning and how/if design modifications impact performance. These assessments were performed at households identified as having alternative on-site sanitation systems and were the same households as those included in the survey. The technical assessment aspect includes sanitation system observations, collection of wastewater effluent, influent, and well water, as well as *in* situ and laboratory analysis.

It was essential that the technical assessment be performed at the same households undergoing the household survey, as they had been identified as having an alternative on-site sanitation system when compared to the national standard. Some information to be used in the assessment was gathered through the survey, such as system size and number of users, but it is the analysis portion of the technical assessment that investigated the compliance of the systems in terms of wastewater quality indicators.

Technical Observation

Prior to sampling, technical observations were performed at each household surveyed. Observations were performed in accordance with an observation form seen in Appendix B. Alongside this observation sheet, technical designs, if provided by stakeholders, were used to determine if the installed system matches that of the planned design. Any discrepancies were noted and were taken into consideration when determining the potential performance effects that design alterations have on alternative on-site sanitation systems.

Sample Collection

Samples were collected for each on-site sanitation system that underwent the surveys and technical observations. Each individual system was subjected to the same grab sample effluent collection procedure as follows.

All of the sanitation systems utilized pour- or cistern-flush user interfaces, and this design factor was used to collect the effluent. During a pilot study with Intertek, the Indonesian contracted laboratory used for analysis, cleansing water was poured into the squat plate until a small outflow stream was seen at the point of effluent discharge for the sanitation system. All systems assessed in this project directly discharged wastewater into the environment without further treatment from leach fields or other mechanisms, and individual systems were chosen based on accessibility and availability of this discharge point. This procedure allowed for collection of effluent without the need for long-term composite sampling to reach the required volumes and to facilitate timely processing and analysis for wastewater quality indicators. Most Indonesian households contain *bak mandi*, or cleansing water tanks, in the vicinity of latrines and these were used in the sample collection procedure. Water used for this procedures was that typically used for anal cleansing, which was prevalent in all households sampled during this study. The volume used was the minimum volume required to allow effluent discharge and this varied across individual systems. Sampling was performed using APHA Method 1060B, with storage and preservation methods outlined below (APHA, 1998). Sampling at the point of discharge into the environment is important in assessing environmental and public health implications of wastewater quality, and the methods used provided a route in which to access that wastewater stream.

Using the effluent, the following measurements were made in the field during each sampling event: pH (accuracy ± 0.2 units), dissolved oxygen (± 0.3 mg/L), and temperature (± 0.3°C), using a YSI Model 63 pH, conductivity, salinity, and temperature system, as well as a YSI Model 550A Dissolved Oxygen System. These meters were calibrated as per the operating manual instructions prior to sample collection. The *in situ* analysis of these measures were performed in response to the field sampling procedures laid out by the contracted laboratory who provided the field equipment.

Grab samples were collected by hand where accessible or by using a pole and container apparatus when needed. Effluent sample collection procedures for the laboratory analysis includes:

- Biochemical oxygen demand (BOD): 1000mL were collected in a clean polyethylene bottle with no preservative.
- Chemical oxygen demand (COD): 250mL were collected in a clean polyethylene bottle. H_2SO_4 was added to preserve the sample.

- Total suspended solids (TSS): 250mL were collected in a clean polyethylene bottle with no preservative.
- Oil and grease: 500mL were collected in an amber glass container. H_2SO_4 was added to preserve the sample.
- Total coliform and *E. coli*: 100mL were collected in a 125mL sterile polycarbonate bottle, with some air remaining in the bottle. The bottle was prepared with $Na_2S_2O_3$ prior to sample collection to preserve the sample.

Influent sampling used identical sampling procedures, with the addition of:

- Surfactants: 1000mL were collected in a clean polyethylene bottle with no preservative.
- Chlorine: 250mL were collected in a clean polyethylene bottle with no preservative.

Well water samples were collected using only the procedures laid out for total coliform and *E. coli* sample collection.

In situ sample collection and analysis was performed for fecal sludge settling and fecal sludge accumulation. Fecal sludge settling was measured by agitating the contents of the sanitation system, collecting 1000mL, and transferring that mixture to a 1000mL graduated cylinder (Figure 8). The settled solid volume was measured every five minutes for up to 30 minutes to attain a settleability measurement, settled sludge volume (SSV_{30}). To measure fecal sludge accumulation, a thin strip of bamboo was inserted into an opening in the system, either a desludging pipe or access cover, if accessible (Figure 9). The height of the fecal sludge was measured using the height of solids retained on the bamboo stick.

Figure 8. Fecal Sludge Accumulation Access

SAMPLE PROCESSING

Following sample collection, all samples were kept on ice and transported to the laboratory to perform analysis within 8-12 hours. For microbial analysis, it is recommended that samples be processed within 8 hours, and during this study, issues in transportation logistics resulted in slight delays in processing and was considered during the analysis and discussion.

Figure 9. Fecal sludge Settling Apparatus

All of the sample processing and analysis was performed by Intertek, a nationally certified lab located in Jakarta, Indonesia. Alongside each batch of samples processed, quality control measurements were performed to ensure accuracy and precision of results. The analyses performed by type of sample are seen in Table 5. The methods used by the laboratory can be seen in Table 6. These methods are commonly used wastewater analyses determined by the American Public Health Association.

Table 5. Analyses Performed

■ = Analysis performed

Sampling Location		Chemical & Biological								Physical		
		E. coli and TC	BOD_5	COD	TSS	pH	Chlorine	Surfactants	Fats/Oils	Temperature	Sludge Settling	Sludge Accumulation
Sampling Location	Effluent	■	■	■	■	■			■			
Sampling Location	Influent		■	■	■		■	■	■			
Sampling Location	Sludge Chamber									■	■	■
Sampling Location	Shallow Well	■										

Table 6. Analyses and Methods of Wastewater Analysis (APHA, 1998)

Measurement	Technique	Method
pH	In situ probe	APHA 4500-H+ B
Dissolved Oxygen, DO	In situ probe	APHA 2510 B
Chlorine	Probe	APHA 4500 Cl I
Total Coliform/E. coli	Enzyme Substrate – Multiple Tube Fermentation (MPN/100mL)	APHA 9223 B / 9221 E
Chemical Oxygen Demand, COD	Closed Reflux, Titrimetric	APHA 5220 C
Biochemical Oxygen Demand, BOD	5-Day Incubation Period	APHA 5210 B
Oil and Grease	Gravimetric	APHA 5520 B
Total Suspended Solids, TSS	Gravimetric	APHA 2540 D
Surfactants, MBAS	Colorimetric	APHA 5540 C

QUALITY CONTROL

For *in situ* analysis, the YSI 63 and YSI 550A meters were calibrated prior to use as instructed by the operation manual. Samples were collected in clean bottles, as provided by the laboratory, and coliform samples were collected in sterile, sealed bottles with the required preservatives. Field technicians performing the sample collection wore gloves and took necessary precautions to minimize the risk of sample contamination. All samples were kept on ice and transported to the laboratory within 8-12 hours. Laboratory analysis was performed by a nationally accredited Indonesian laboratory. The laboratory had a robust quality control and assurance policy and participated in audits, proficiency testing, method validation, and all accreditation requirements, as needed. Alongside each sample batch processed, quality control measurements were performed to ensure precision and accuracy of measurement, checking both instrument and technician calibration and quality. One in every ten samples was run in duplicate to ensure proper sampling procedures and analysis. All quality control measurements were within the limits of: ± 5% calibration check standard, ± 15% reference material, ± 15% laboratory replicate, and a blank below the limit of detection for the analysis performed.

Key Stakeholder Discussion Analysis

A thematic analysis approach was used for analysis of stakeholder discussion transcripts. Common themes across stakeholders were compared, and any discrepancies were evaluated. Recommended points of consideration are discussed as introduced by stakeholders. Any technical recommendations provided in regards to alternative on-site sanitation systems are analyzed and interpreted alongside effluent quality data to provide a narrative of stakeholder-recommended designs in relation to those sampled and analyzed in this study.

Statistical Analysis

A total of ten on-site sanitation system designs were utilized for sample collection, which were combined into nine different categories. For analysis, the systems were combined into appropriate categories based on similar designs and technology used. The nine categories are

(1) 3 Filter Septic Tank, (2) 1 Filter cylindrical Septic Tank, (3) 2 Filter Floating Septic Tank, (4) Concrete Cylindrical Septic Tank, (5) 1 Filter Floating Septic Tank, (6) One Container Septic Tank with Anaerobic Up-Flow Filter (ST+AUF), (7) Two Vertical-Container ST+AUF, (8) Two Horizontal-Container ST+AUF, and (9) SNI Modified Septic Tank. These is discussed in further detail in the results section.

64 effluent samples were collected in total, along with 2 influent samples and 3 well water samples. The number of samples per category varied, with a range between 5 and 19, due to limited availability of viable systems. Due to the small sample size per category, greater uncertainty is expected, indicated by wide confidence intervals, non-normal distributions, and less statistical power. Normality was assessed using the univariate command with the normal option using SAS 9.3.

Descriptive and bivariate analysis were used for households and systems included in the study to provide basic measures of system performance by category. Descriptive statistics were also used to assess the outcomes of interest across sanitation system designs. To assess differences in treatment by effluent quality variables and design, multiple one-way analysis of variance (ANOVA) tests were performed using the Tukey approach for pairwise comparisons.

Linear regression analysis was used to evaluate treatment factors across the nine design categories. Simple linear regression was performed to examine the impact of potential predictor variables on each treatment factor, as well as to look at the effects that treatment factors may have on other treatment factors. Ridge regression was utilized to evaluate treatment indicators by design factors alongside potential predictor variables, such as number of household members, age of system, and others. Ridge regression is an ideal method to account for collinearity between predictor variables, which was seen in many included in the regression model (Table 21 Appendix C). Ridge regression utilizes a tuning factor (shrinkage factor), λ, which controls the regularization and size of coefficients in the model to address multicollinearity in the model predictor variables. λ serves as a penalty factor which aims to balance residual sum of squares and λ itself so as to lower the cross validation error used in λ selection. Ridge regression uses the formula: $\widehat{B}_{\lambda}^{ridge} = \left(X'X + \lambda I_p\right)^{-1} X'Y$, where X is standardized and Y is centered (Hoerl and Kennard, 1970). Selection of λ is an important step in ridge regression, as it impacts the coefficients of independent variables in the model. As λ increases towards infinity, the coefficients approach zero and the model is essentially an intercept only model. As λ approaches zero, the model becomes the least squares solution. There are many methods of choosing the appropriate λ, but for this regression λ was chosen using generalized cross validation (GCV) error (Golub *et al.*, 1979).

Well water samples were used to evaluate what can be considered background levels of total coliforms and *E. coli* in an area that one would not expect contamination due to sanitation systems. Influent samples were utilized in calculating percent reductions in treatment indicators, where appropriate.

RESULTS

STAKEHOLDER DISCUSSIONS

Discussions with relevant stakeholders in the sanitation sector allowed for opinions and knowledge to be shared with those most involved with on-site sanitation systems in Indonesia. Many discussions resulted in similar thoughts and suggestions considering the sanitation systems studied and sanitation in general, and the following key-points are considered the important takeaways from the meetings.

WASTEWATER QUALITY INDICATORS

Nutrients: One common theme in regards to the important indicators of wastewater effluent quality was the potential effects that nutrients can have on groundwater and surface water. Stakeholders suggested that phosphate, nitrate, and NH_4 can negatively impact water sources, both for the health of the community and the environment These nutrients have also been found to not be addressed well by anaerobic treatment systems, such as anaerobic filters or conventional septic tanks. The importance of nutrient analysis in effluent was stressed multiple times, and although not included in this study, it should be considered in future analyses to determine the holistic impact wastewater effluent can have on the environment.

***E. coli* and Total Coliforms:** Conflicting thoughts arose between stakeholders around the testing of fecal coliforms and *E. coli,* with some stressing it's importance in analysis and others negating its importance. One stakeholder explained that their thought process on excluding the analysis of E. coli or fecal coliforms was due to the fact that they would be present in all environments throughout Indonesia due to the tropical environment and natural sources. It was noted that it would be hard to determine the source of the E. coli and to attribute any potential well water contamination with fecal indicators to the sanitation system. The problem of E. coli and fecal coliforms present in effluent was described as an easy one to fix with a cheap disinfectant mechanism, such as tablet dosing systems that cost approximately 25,000 IDR. The problems of high BOD and TSS were thought to be much more difficult to solve and thus more important in testing and analysis.

In discussions with another stakeholder, the importance of both E. coli and fecal coliform testing was stressed. They stated that not simply the presence or absence of these factors is important, but that knowing the most probable number (MPN) of each coliform was necessary.

Fecal Sludge Characteristics: Other methodology suggestions were related to the sludge characteristics and sludge/scum accumulation. It was recommended that the sludge accumulation be measured, as well as other sludge characteristics such as sludge settling volume (SSV). In regards to sludge characteristics, it was proposed that the sludge settling values of the influent would be more beneficial than that of the sludge in the tank since this would be a better indicator of how the waste would react and settle out in the sanitation system. One stakeholder also suggested only testing the sludge settleability for a limited number of tanks in a certain area, as they thought the characteristics would be similar between households.

Sanitation Systems

Stakeholders were essential in locating alternative on-site sanitation systems currently in use throughout Indonesia and provided locations and recommendations based on their knowledge and experience. Not all systems that were included in the technical analysis were discussed with stakeholders, and those that were are discussed below.

Type 1: For system Type 1, the developer was included in the stakeholder discussions and allowed for insight into the design and operation of the system. This design contains three separate media filter chambers and typically use locally available material as the filter media (Figure 10). These can include plastic hair curlers, discarded fishing net that is woven into thick netting, and other plastic materials from discarded solid waste. The use of hair curlers has similar impacts to bioball media although the hair curlers cost significantly less and can be purchased locally.

Figure 10. Type 1 Model – 3-filter septic tank

Type 2: While we did not meet with the developer or provider of Biofil systems, other stakeholders had comments about the design and performance of the system that would be helpful during the planning and evaluation of the investigation. During the discussion with one stakeholder, the design of the system was found to include one filter per tank which primarily consists of PVC media. The use of PVC as opposed to bioball or kaldnes media lowers the available surface area for anaerobic digestion to occur, although a potential reason behind the use of PVC as filter media could be to keep the price low and affordable for more households. The volume of the system was explained to be approximately 1000 liters (1.0m^3) with a cost of approximately 500 USD (6.7 million IDR) per system. Also noted was that this system was not certified by the Government of Indonesia. During discussions with one stakeholder, the progression of system development was found to be from Type 2 → intermediate → Type 1. The improvements progressed through the number of media filters as well as the type of media used, starting from PVC and moving to more local and sustainable materials.

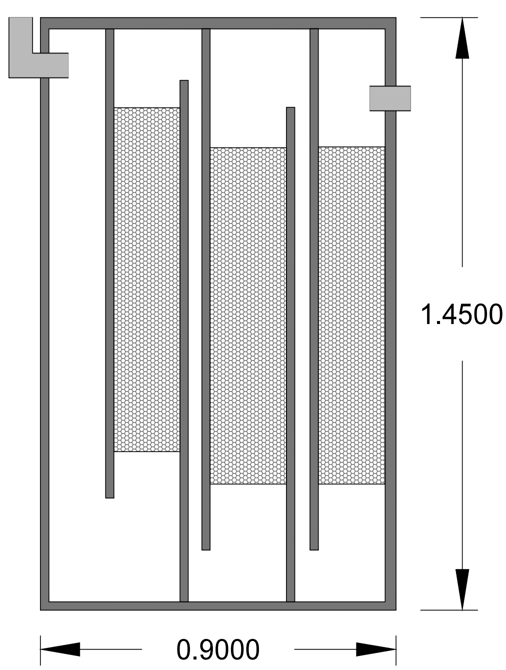
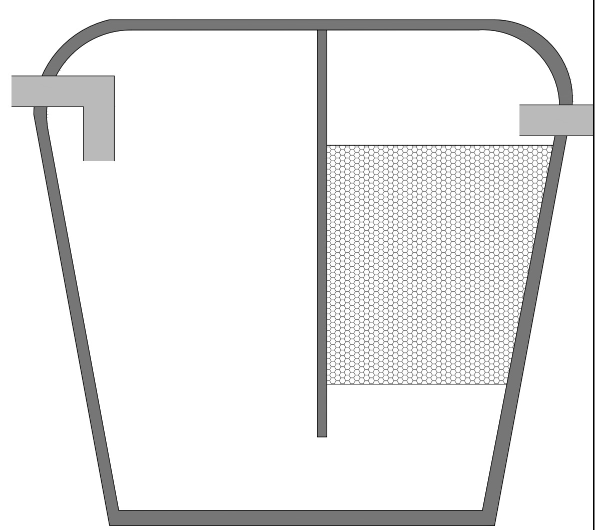
Type 3: During the discussion with the developers of the Type 3 system, we were able to gather data pertaining to the design and performance of the system as well as the thought process that went into the design, as seen in Table 7. This system is a 600 liter ($0.6m^3$) septic tank system with two filters. The two filter chambers and the other design parameters of the system allow for a typical desludging period of 2-3 years, with some able to stretch to every 5 years due to sludge digestion and optimal conditions. According to the developer, the treatment efficiency of the system is guaranteed to meet the national wastewater effluent standards when operated under the specified conditions, and the guarantee comes with an obligation to the provider to replace or upgrade the system if it is not meeting the standards. The price of the Type 3 system is approximately 400 USD (approximately 5.4 million IDR) for a system that serves one household of between 5-6 people. This includes the biofilter media consisting of bioball, which was estimated to cost 2.5 million IDR per $1.5m^3$ (Figure 11). As quoted by a sanitation system Type 3 manufacturing worker, one bag of bioball costs approximately 30,000 IDR and for the individual system, 20 bags are needed, resulting in a total cost of 600,000 IDR per system for media. This system is also a government certified sanitation system readily available for implementation in communities around Indonesia.

Figure 11. Bioball Filter Media

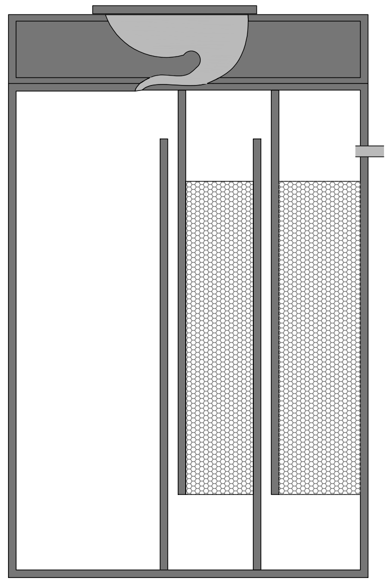
Type 8: Based on the comments from one stakeholder, this system was estimated to have a capacity of 1500 liters ($1.5m^3$) with a HRT of approximately 20 hours, and the developers explained that volumes ranged from 1 – 2m^3 based on the area of implementation. The cost was thought to be approximately 100 USD (4.5 million IDR) for both labor and materials. The developer indicated that the filter was comprised of PVC, and that the system is constructed with prefabricated concrete slabs that are sealed together on-site.

All Identified Systems: Table 7 below shows the designs of the selected systems included in the analysis of effluent quality. These systems were identified through stakeholder discussions as well as community transect walks with community leaders in the various study sites. The categories of systems have distinct design factors that define them, as discussed below.

Table 7. Selected Alternative On-Site Sanitation Systems

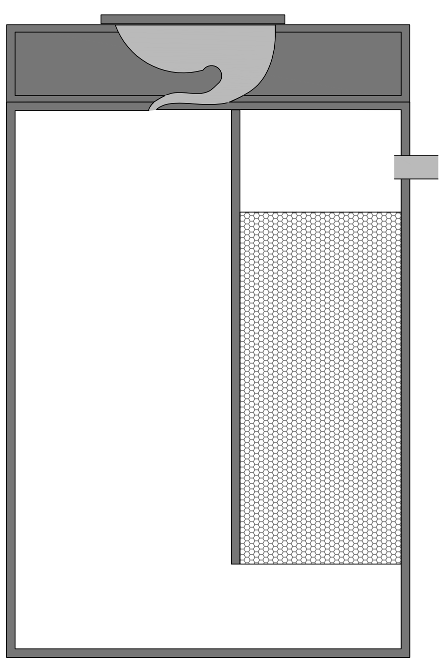
Type 1	Type 2
	

Type 3

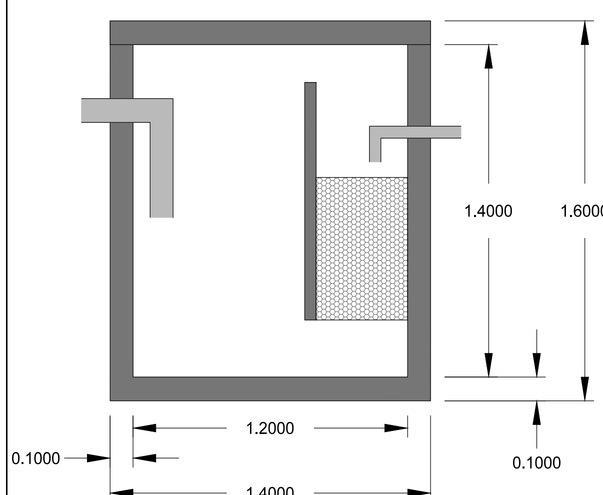


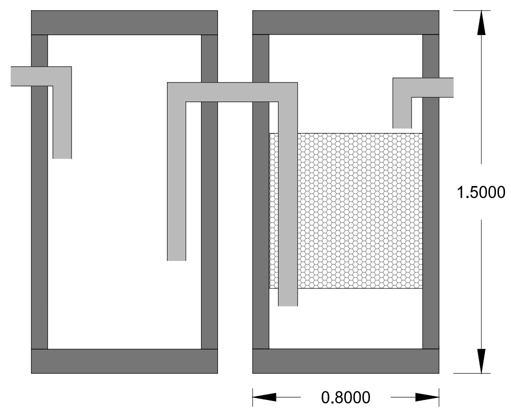
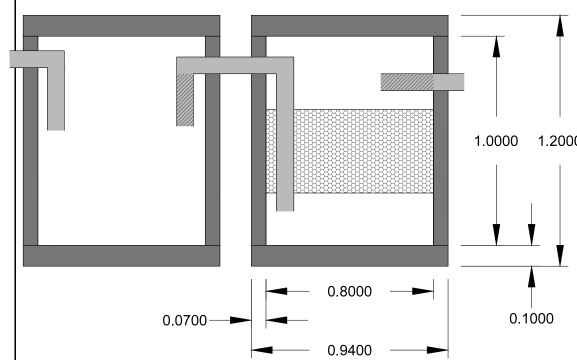
Type 4

Type 5



Type 6



Type 7	Type 8
	
Type 9	
SNI Modified Design	

Type 1: Type 1 is a fiberglass septic tank separated into four compartments by baffles (Figure 12). This system consists of three anaerobic filter units, each made up of different filter media. The first chamber acts as a settling chamber before altering the wastewater flow into a vertical flow through the first media filter, typically made up of locally available discarded plastic material. Baffles then direct the flow through the remaining up-flow anaerobic filters, made up of media such as woven fishing nets and hair curlers. This system is unique in that it has three anaerobic filter units each with different media. This is also a comparatively small system, with a volume of $0.75m^3$ designed to serve 4-6 people. This system utilizes a tee design on the influent pipe but not on the effluent pipe.

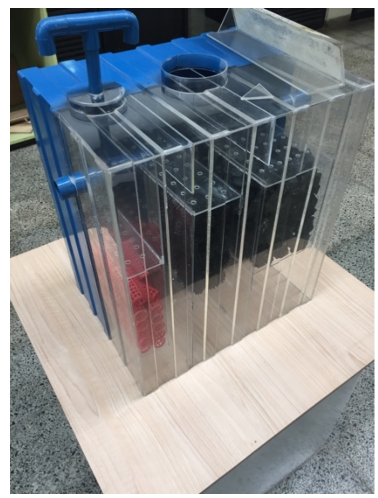


Figure 12. Type 1 Model (side view)

Type 2: Type 2 is a fiberglass container-based package septic tank system that consists of two chambers, separated by a hanging baffle, all located in one container. The first chamber acts as a settling chamber which also directs wastewater flow upward through the following anaerobic up-flow filter. The media filter in the filter unit typically consists of small, cut up PVC pipe. The first and second chamber are separated by a hanging baffle, which allows wastewater as well as fecal sludge to travel between them. Desludging is expected to typically occur in the first chamber, as that is where the desludging pipe is located. This system comes in three variations, with volumes of $0.8m^3$, $1.0m^3$, and $1.85m^3$ for those serving between 2-4, 2-5, and 4-6 people, respectively. For this study, only systems with a volume of $1.0m^3$ were located and included in analysis. This system also utilizes a tee inlet but lacks a tee outlet pipe.

Figure 13. Sanitation System Type 3 - Typical Installation

Type 3: Type 3 is a fiberglass septic tank system consisting of three chambers and two anaerobic filter units. This system has blackwater entering the system directly from a pour-flush squat plate above the tank and has an additional inflow pipe in the first chamber. The first chamber acts as a settling chamber which extends below the two following chambers, with a desludging pipe located near the outflow pipe. The following two chambers are separated by baffles that direct wastewater upwards through anaerobic filters that utilize bioball as filter media media (Figures 14 and 15). This system has a volume of $0.60m^3$ and is expected to serve 5-6 people. This system lacks a tee design on both influent and effluent pipes, and

Figure 15. Sanitation System Type 3 - Top View (Flow from left-to-right)

Figure 14. Sanitation System Type 3 (No filter media)

the main inflow mechanism is directly from the squat plate to the first chamber. This tank is typically installed into the floorboards of a house that is situated above water or on a riverbank (Figure 13). These have also been used in floating houses as long as they are properly anchored so buoyancy does not cause issues with long-term operation.

Type 4: Type 4 is a prefabricated concrete septic tank consisting of two chambers separated by a closed baffle. The container of this system is approximately 2.5m long with a diameter of approximately 0.7m. The first chamber is 2/3 of the volume with the second chamber consisting of 1/3, with an overall system volume of $0.45m^3$. This system was designed to accommodate up to 5 household members and is a similar design to that of the SNI design with minor variations. This also utilizes tee designs on all pipes, including influent, effluent, and the chamber exchange pipe.

Type 5: Type 5 is a fiberglass septic tank consisting of two chambers and one anaerobic filter unit (Figure 16). This system is similar to Type 2 with the modification of being a rectangular design with a pour flush squat plate directly above the tank.

Figure 16. Sanitation System Type 5 - Typical Squat Plate

Wastewater directly enters the first chamber from the squat plate and the first chamber acts as a settling chamber for solids. The flow is then directed up through the anaerobic filter comprised of bioball media before flowing out the effluent pipe that is flush with the wall of the tank. Sludge is expected to accumulate primarily in the first chamber where the desludging pipe is located. This system has a volume of $0.48m^3$ and is expected to serve households of approximately 5 people. Type 5 systems, similar to Type 3, are installed primarily in housing above water and in tidal areas.

Figure 17. Sanitation System Type 6

Type 6: Type 6 is a concrete septic tank, built on-site, consisting of two chambers separated by a floating baffle (Figure 17). This system uses a tee inlet pipe leading to the first chamber, which acts as a settling chamber, before directing the flow upwards through a PVC media filter and out a tee outflow pipe. This type of system comes in three variations, with volumes of $1.70m^3$, $1.98m^3$ and $2.65m^3$, serving approximately 5 people for all sizes. Both systems were located and included in this analysis.

Type 7: Type 7 is similar to type six, consisting of two concrete chambers built on-site with one anaerobic filter unit. The difference is due to the layout of the two chambers, with each located in a separate concrete tank. The first tank serves as a settling chamber with the second acting as an up-flow filter, with typical media including both bamboo and PVC. The first tank is where the majority of sludge accumulation is expected to occur and the design includes a manhole cover for desludging access. This system has two different volumes, $1.17m^3$ and $2.46m^3$ expected to serve approximately 4-5 people.

Type 8: Type 8 is a system comprised of prefabricated concrete slabs which are sealed on-site to construct the two separate tanks. This type is very similar to Type 7, with the exception of volume, dimensions, and filter attachments on the pipe separating the two tanks and the effluent pipe. Sludge accumulation is expected to occur in the first tank which acts as a settling tank and is where the desludging pipe is located (Figure 18). The second tank acts as an up-flow anaerobic filter with PVC material as the filter media. This system has an approximate volume of $1.0m^3$ to serve 4-5 people.

Figure 18. Sanitation System Type 8

Type 9: Type 9 is the conventional, Indonesian National Standard design, SNI 03-2398-2002. This is very similar to system Type 4, although dimensions and internal design factors differ. This is a concrete system, built on-site with a diameter of 1m and a depth of 1.5m. This system has a tee inlet pipe into the first chamber, which is the primary settling chamber. A floating baffle separates this chamber from the second, in which the effluent exits through a tee baffle. This design is the cylindrical tank defined as the "tangki septik modifikasi" in the SNI design. This system type is important for comparisons of other alternative designs to that of the nationally accepted standard design.

STATISTICAL ANALYSIS

Systems were compared using statistical tests that are explained by effluent quality indicator in the sections to follow.

Demographics

Table 8 below shows a summary of the household demographic and system characteristics for those included in the analysis. Overall, 57 households and systems were included in the analysis after removing outliers based on effluent quality indicators and the range given by the formula: $([Q1 - 3IQR], [Q3 + 3IQR])$, where Q1 equals the first quartile, Q3 equals the third quartile, and IQR equals the interquartile range. This formula was used to assess effluent quality variables for each type and those systems that had an outlier for any variable were removed from the overall analysis and is discussed separately. By doing so, this allows for assumptions to be based on the performance of similarly functioning systems without the large effect of outliers on small sample size, but it is important to consider the implications of outliers for each type of system in regards to performance.

As shown in Table 8, all of the systems included in analysis are located in three main areas: Medan, Bandung, and Jakarta. The households and sanitation systems within these areas are dispersed across urban, peri-urban, rural, and tidal areas, and these differed significantly by type of system ($p<0.0001$). Household type and status also differed significantly across sanitation system types, with p-values of <0.0001 and 0.0022, respectively. An important factor in the design and performance of sanitation systems are the number of users, and the households included in the analysis did not differ significantly in regards to the number of household members by type of system ($p=0.1104$). Desludging also has the potential to impact performance, and of the systems included in the study, there was no significant difference in those that had been desludged versus those that have not ($p=0.6539$).

Table 8. Household and System Demographics by Sanitation System Type

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9	p (Fisher's Exact Test /ANOVA)
n	6	6	3	8	4	7	4	13	6	-
Location(s)	Cimahi, Bandung	Bandung	Medan	West Jakarta	Medan	Medan, Bandung, Tangerang	Bandung, Tangerang	West Jakarta	Bandung	-
Age (mean (sd))	37.3 (11.4)	27.2 (8.4)	55.0 (17.1)	34.9 (13.9)	51.5 (6.9)	47.7 (16.3)	48.0 (14.2)	42.4 (9.0)	48.3 (13.3)	0.0123
Sex (%)										0.0855
Male	66.7	16.7	33.3	12.5	75.0	14.3	0.0	53.9	50.0	
Female	33.3	83.3	66.7	87.5	25.0	85.7	100.0	46.2	50.0	
Household Type (%)										<0.0001
Permanent (brick, concrete, etc.)	100	100	-	100	-	28.6	25.0	84.6	100	
Semi-Permanent (wood, steel sheets, etc.)	-	-	100	-	75.0	57.1	75.0	15.4	-	
Don't Know	-	-	-	-	25.0	14.3	-	-	-	
Housing Status (%)										0.0022
Owned	100	100	33.3	87.5	-	85.7	100	53.9	100	
Rented	-	-	-	12.5	25.0	-	-	7.7	-	
Shared	-	-	66.7	-	75.0	14.3	-	38.5	-	
Household Location (%)										<0.0001
Urban	100	100	-	100	-	-	-	100	100	
Peri-Urban	-	-	-	-	-	57.1	75.0	-	-	
Rural	-	-	-	-	-	28.6	25.0	-	-	
Tidal Area	-	-	100	-	100	14.3	-	-	-	
Number of Household Members (mean (sd))	3.5 (1.4)	4.5 (1.4)	5.3 (2.1)	4.5 (2.1)	6.0 (1.8)	5.6 (2.1)	6.5 (4.4)	3.8 (1.0)	3.5 (1.6)	0.1104
Age of System (mean (sd))	1.0 (1.1)	3.3 (2.8)	3.5 (3.5)	2.1 (1.1)	2.0 (0.0)	1.3 (0.5)	1.8 (0.5)	6.4 (1.9)	1.6 (0.6)	<0.0001
Number of Filters (n)	3	1	2	0	1	1	1	1	0	
Systems Desludged (n)										0.6539
Systems Emptied	-	1	-	1	-	-	-	1	-	
Systems not Emptied	6	4	3	6	3	7.0	4	12	6	
Don't Know	-	1	-	1	1	-	-	-	-	

TREATMENT FACTOR ANALYSES

Table 9. Summary of Wastewater Effluent Quality Indicators by Sanitation System Type

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9
n	6	6	3	8	4	7	4	13	6
BOD (mg/L)	188.67 (70.58)	153.83 (99.59)	497.00 (29.72)	273.25 (228.55)	232.0 (15.38)	219.14 (74.48)	229.50 (86.93)	183.46 (133.25)	118.00 (58.17)
COD (mg/L)	558.00 (220.75)	458.33 (300.26)	1463.33 (70.24)	882.13 (764.80)	719.75 (63.13)	696.00 (223.97)	725.75 (298.52)	517.62 (391.87)	356.17 (173.74)
TSS (mg/L)	68.17 (29.62)	86.50 (61.59)	420.00 (55.75)	295.13 (172.20)	216.00 (301.03)	81.86 (56.81)	387.25 (573.95)	119.54 (143.32)	123.67 (127.61)
Oil and Grease (mg/L)	33.33 (36.26)	16.67 (13.19)	69.67 (25.89)	102.25 (114.72)	22.25 (7.09)	16.71 (5.94)	13.00 (6.06)	17.08 (11.61)	10.67 (7.53)
***E. coli* (MPN/100mL)**	8226.67 (1578.59)	7328.33 (1104.92)	10423.33 (2904.07)	10881.25 (1779.22)	8847.50 (2797.59)	7340.00 (2536.54)	7170.00 (2628.78)	6976.15 (1793.24)	6900.00 (505.45)
pH	7.87 (0.27)	7.64 (0.43)	7.09 (0.10)	6.96 (0.29)	6.92 (0.04)	7.27 (0.31)	7.21 (0.17)	7.37 (0.38)	7.24 (0.50)
Temperature (°C)	26.30 (0.77)	26.05 (0.39)	29.47 (1.32)	30.43 (0.48)	29.67 (2.01)	27.31 (3.07)	25.78 (2.34)	28.25 (0.66)	27.35 (1.14)
Sludge Depth (cm)	0.01 (0.00)	-	52.67 (45.78)	4.67 (2.52)	52.50 (40.87)	48.25 (57.97)	33.13 (31.59)	84.31 (5.01)	22.50 (18.06)

BOD AND COD

BOD and COD are highly correlated wastewater quality indicators, and this was seen with the effluent data collected (Pearson Correlation Coefficient = 0.9913). Overall, mean BOD levels were found to be 214.12 mg/L and mean COD levels were 650.26 mg/L. Disaggregating the data by sanitation system type allows for comparisons to be made in regards to treatment, and Figure 19 below shows the mean BOD and COD levels by type of system, with standard deviations shown as error bars. Levels varied by sanitation system type, with some discernable patterns based on the figure. Highest for both BOD and COD was Type 3, with mean levels of 497.00 mg/L BOD and 1463.33 mg/L COD. The lowest levels for both measures were seen in Type 9, with mean BOD levels of 118.00 mg/L and mean COD levels of 356.17. The maximum overall BOD level was 669.00 mg/L, where the

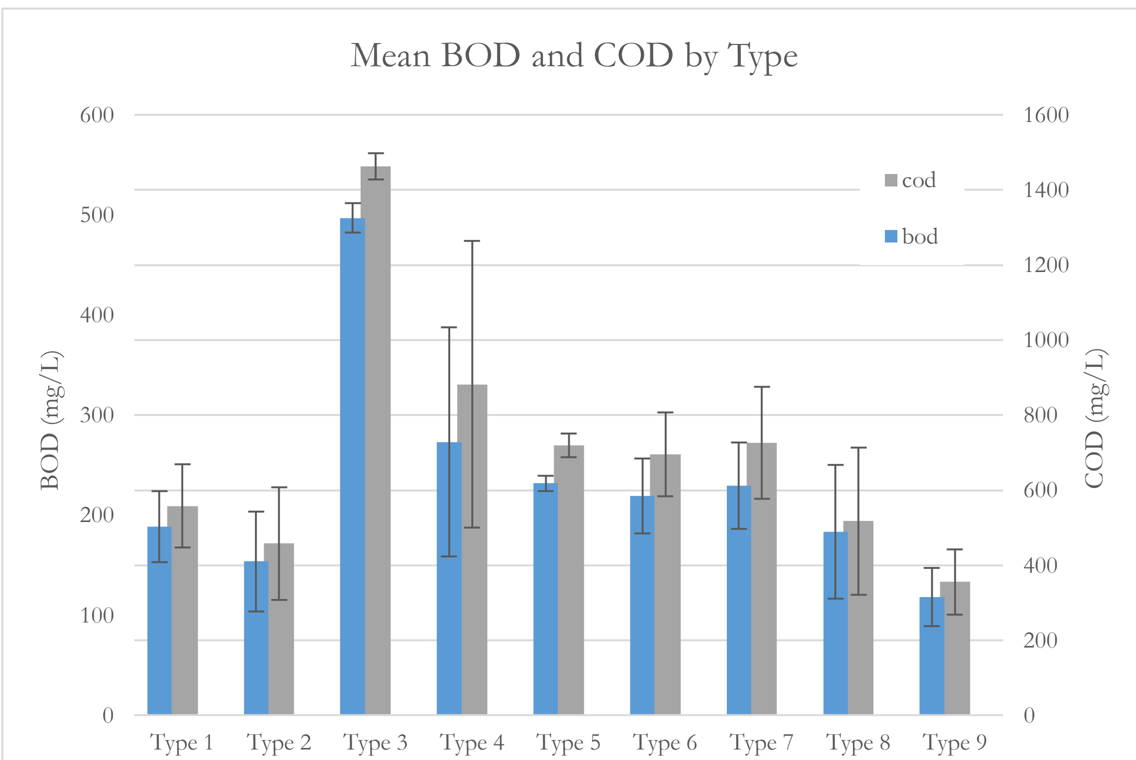


Figure 19. Mean Biochemical Oxygen Demand and Chemical Oxygen Demand by Sanitation System Type (Standard Deviation Error Bars)

minimum was 19.00 mg/L, and for COD the maximum was 2340.00 mg/L with a minimum of 53.00 mg/L.

Multiple one-way ANOVA tests using the Tukey approach were performed to assess relationships between the type of sanitation system and the BOD and COD. Figures 20 and 21 below show the distribution of BOD and COD by type of sanitation system.

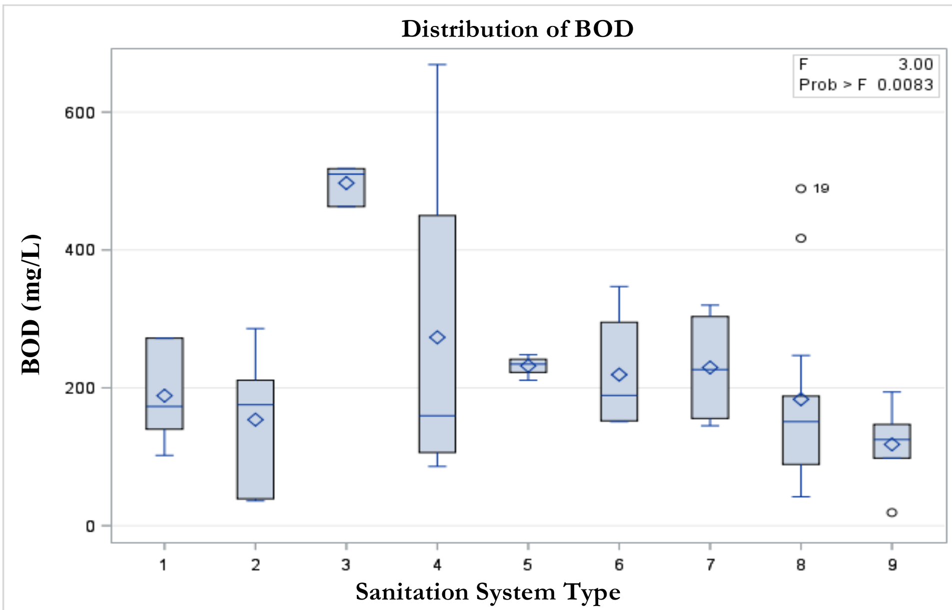


Figure 20. Distribution of BOD by Sanitation System Type

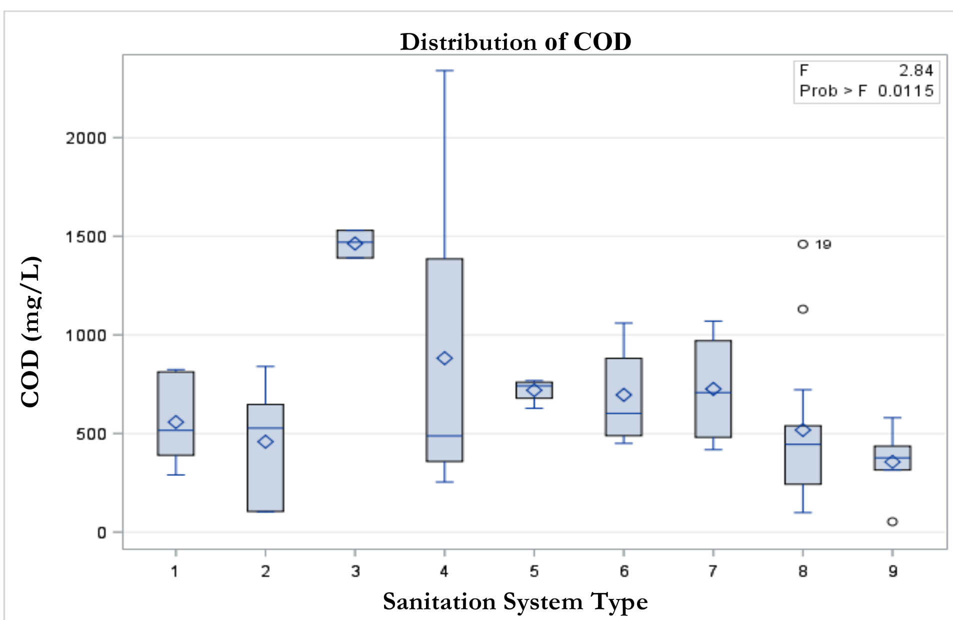


Figure 21. Distribution of COD by Sanitation System Type

The type of sanitation system explained 33% of the variability in BOD levels of wastewater effluent, with an R^2 value of 0.3330 (F-test p-value = 0.0083). A similar statistically significant finding was seen with COD, where the type of system explained 32 % of the variability in COD (R^2 = 0.3213, F-test p-value = 0.0115). Looking at the performance of individual systems, Type 3 wastewater effluent had significantly higher levels of BOD than Type 1 (mean difference (3-1)=308.33, 95%CI=(25.45, 591.22)) , Type 6 (mean difference (3-6)=277.86, 95%CI=(1.79, 553.93)), Type 8 (mean difference (3-8)=313.54, 95%CI=(57.29, 569.78)), and Type 9 (mean difference (3-9)=379.00, 95%CI=(96.11, 661.89)). For COD, system Type 3 had significantly higher levels than Type 1 (mean difference (3-1)=905.3, 95%CI=(5.4, 1805.2)), Type 2 (mean difference (3-2)=1005.0, 95%CI=(105.1, 1904.9)), Type 8 (mean difference (3-8)=945.7, 95%CI=(130.6, 1760.9)), and Type 9 (mean difference (3-9)=1107.2, 95%CI=(207.3, 2007.1)). See Appendix C Tables 13 and 14 for full tables of results.

TSS

Overall distribution of mean TSS by type of sanitation system can be seen in Figure 22. The mean TSS level for all systems was 172.47 mg/L. The sanitation system with the highest mean TSS level in the wastewater effluent was Type 3 (mean=420.00 mg/L), where the system with the lowest was Type 1 (mean=68.17 mg/L). Overall, the highest TSS value was 1240.00 mg/L where the lowest was 11.00 mg/L.

Multiple one-way ANOVA tests using the Tukey approach were performed to assess relationships between TSS and the type of sanitation system. Figures 23 shows the distribution of TSS by sanitation system type. 28% of the value of the TSS measurement could be explained by the sanitation system type (R^2=0.2791, F-test p-value = 0.0340).

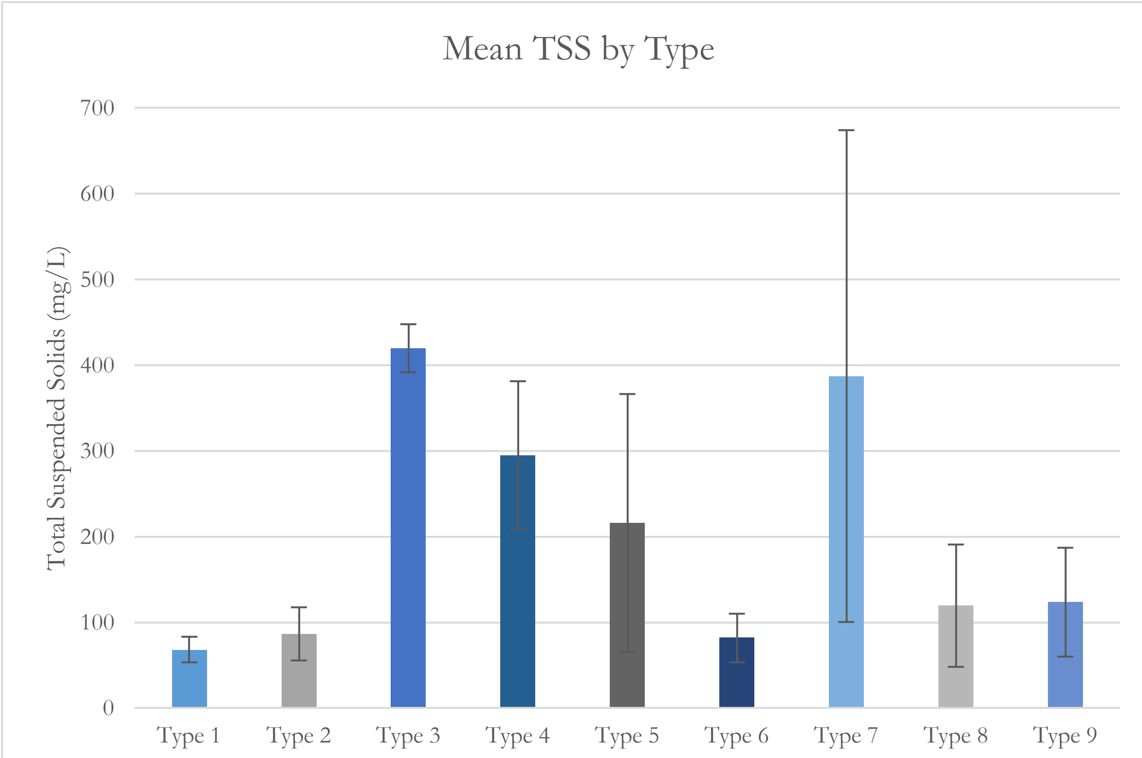


Figure 22. Mean Total Suspended Solids by Sanitation System Type (Standard Deviation Error Bars)

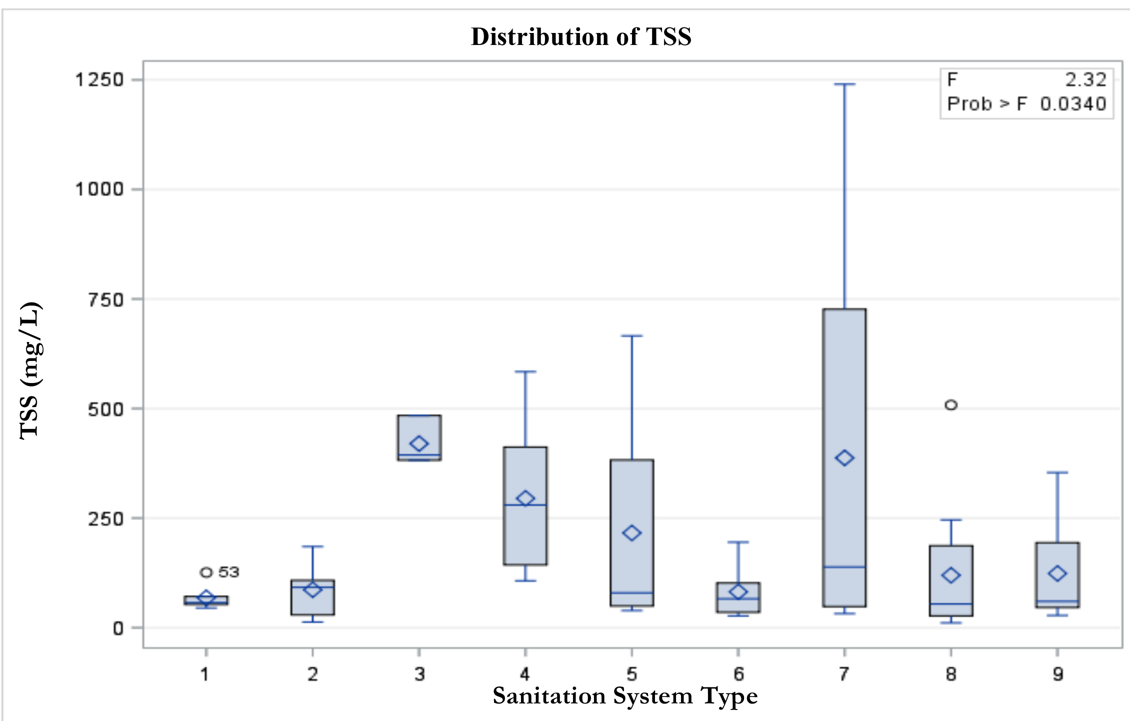


Figure 23. Distribution of TSS by Sanitation System Type

While variability was seen between sanitation system type, no systems had significantly different TSS values as indicated by the Tukey ANOVA approach. Considering within system type and differing volumes, Type 7 systems with volumes of 1.17 and 2.46m^3 differed significantly, with the difference between means of the smaller and the larger being 1137.00 mg/L (95% CI = 568.55, 1705.45). See Appendix C Table 15 for full results.

Oil and Grease

Across all sanitation systems, the mean level of oil and grease was 32.82 mg/L. Figure 24 shows mean oil and grease levels by sanitation system type, with 6 types below the mean level of 32.82 mg/L. System Type 4 had the highest OG levels at a mean of 102.25 mg/L, where system Type 9 had the lowest levels with a mean of 10.67 mg/L. The highest OG level measured was 295.00 mg/L, where the lowest value was found to be 1.00 mg/L.

ANOVA and the Tukey approach show that 34% of the variation of oil and grease levels can be explained by the type of sanitation system, with an R^2 value of 0.3442 and an F-test p-value of 0.0060. Sanitation system Type 4 had significantly higher oil and grease levels when compared to Type 2 (mean difference (4-2)=85.58, 95%CI=(4.23, 166.93)), Type 6 (mean difference (4-6)=85.54, 95%CI=(7.58, 163.49)), Type 8 (mean difference (4-8)=85.17, 95%CI=(17.49, 152.86)), and Type 9 (mean difference (4-9)=91.58, 95%CI=(10.23, 172.93)). Figure 25 below shows the distribution of oil and grease levels across sanitation system types. Seen Appendix C Table 16 for full results.

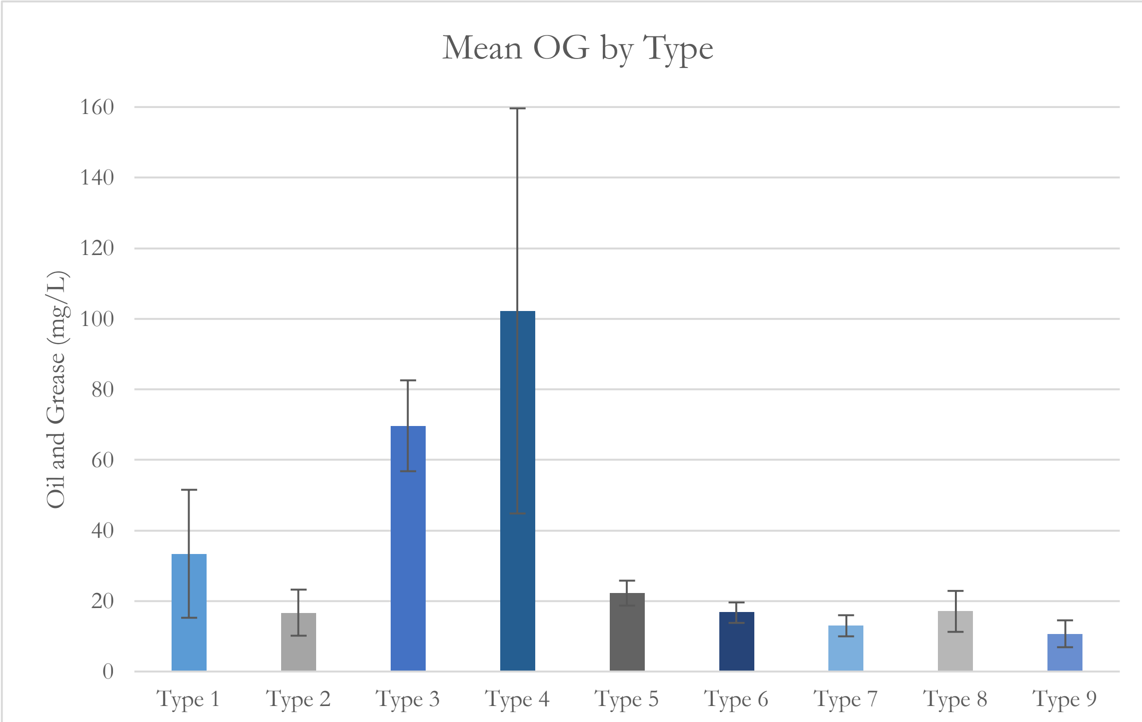


Figure 24. Mean Oil and Grease Levels by Sanitation System Type (Standard Deviation Error Bars)

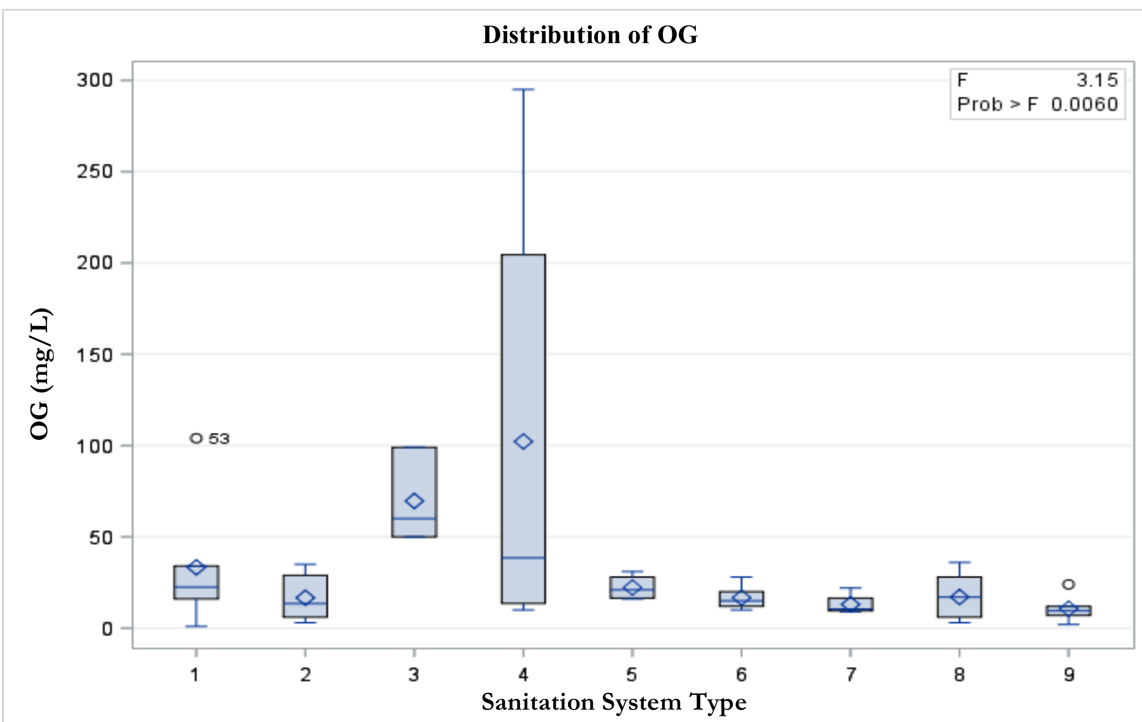


Figure 25. Distribution of Oil and Grease by Sanitation System Type

E. COLI AND TOTAL COLIFORMS

E. coli levels varied by system type, as seen in Figure 26. Total coliforms for all systems were above the limit of detection, 12100 MPN/100mL, and will not be discussed further. Mean levels of *E. coli* across the systems was 8055.96 MPN/100mL. Sanitation system Type 4 had the highest mean level at 10881.25 MPN/100mL, while Type 9 had the lowest mean level at 6900.00 MPN/100mL. Overall the highest measure of *E. coli* was 12100 MPN/100mL (the upper limit of detection), where the lowest was 2110.00 MPN/100mL.

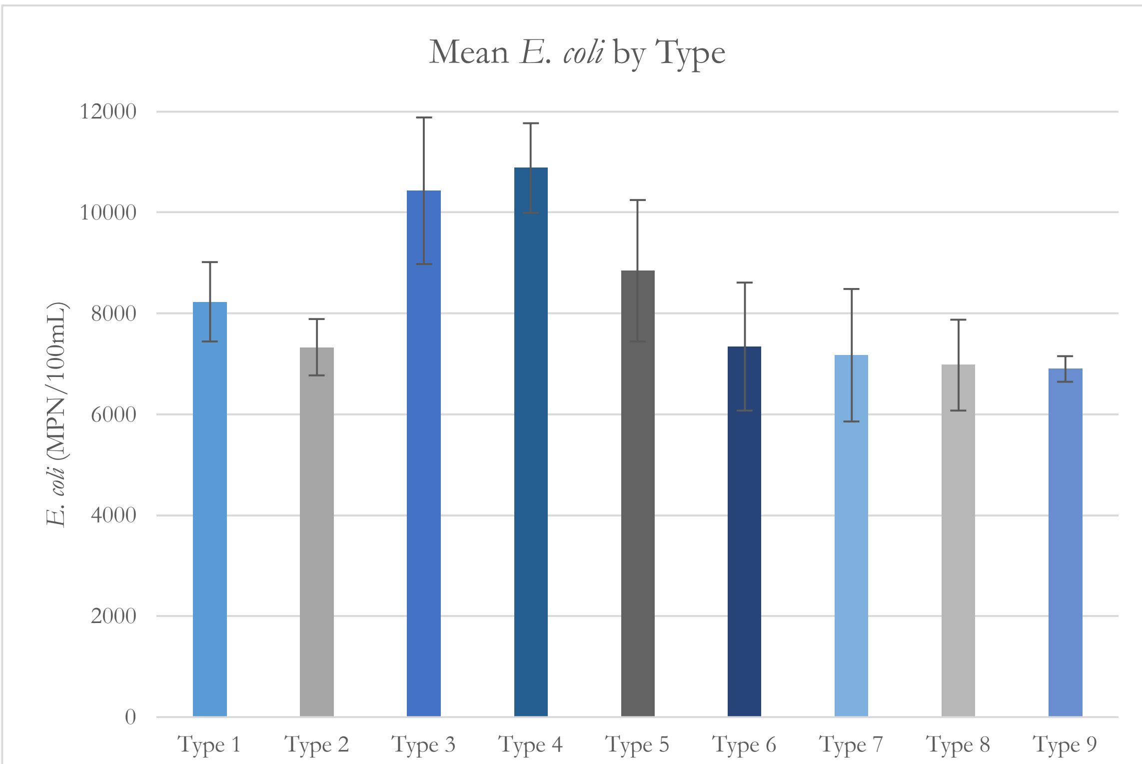


Figure 26. Mean E. coli MPN by Sanitation System Type (Standard Deviation Error Bars)

Figure 27 below shows the distribution of values for *E. coli* MPN/100mL by system type across the 9 systems. Using the ANOVA analysis, it was show that 39% of the variation of *E. coli* values could be explained by the system type (R^2 = 0.3924, F-test p-value = 0.0014). After performing Levene's Test for Homogeneity, it was discovered that *E. coli* variance was not homogenous across sanitation system types, so a Welch's ANOVA was performed, resulting in a statistically significant model (Welch's-test p-value=0.0101). Using the MIXED command in SAS and by adjusting using the Tukey approach due to the heterogeneous variances, individual system types could be compared and Type 4 had higher *E. coli* levels than Type 2 (mean difference (4-2)=3552.92, adjusted p-value=0.0342), Type 6 (mean difference (4-6)=3541.25, adjusted p-value=0.0238), Type 8 (mean difference (4-8)=3905.10, adjusted p-value=0.0014), and Type 9 (mean difference (4-9)=3981.25, adjusted p-value=0.0110). See Appendix C Table 17 for full results.

pH

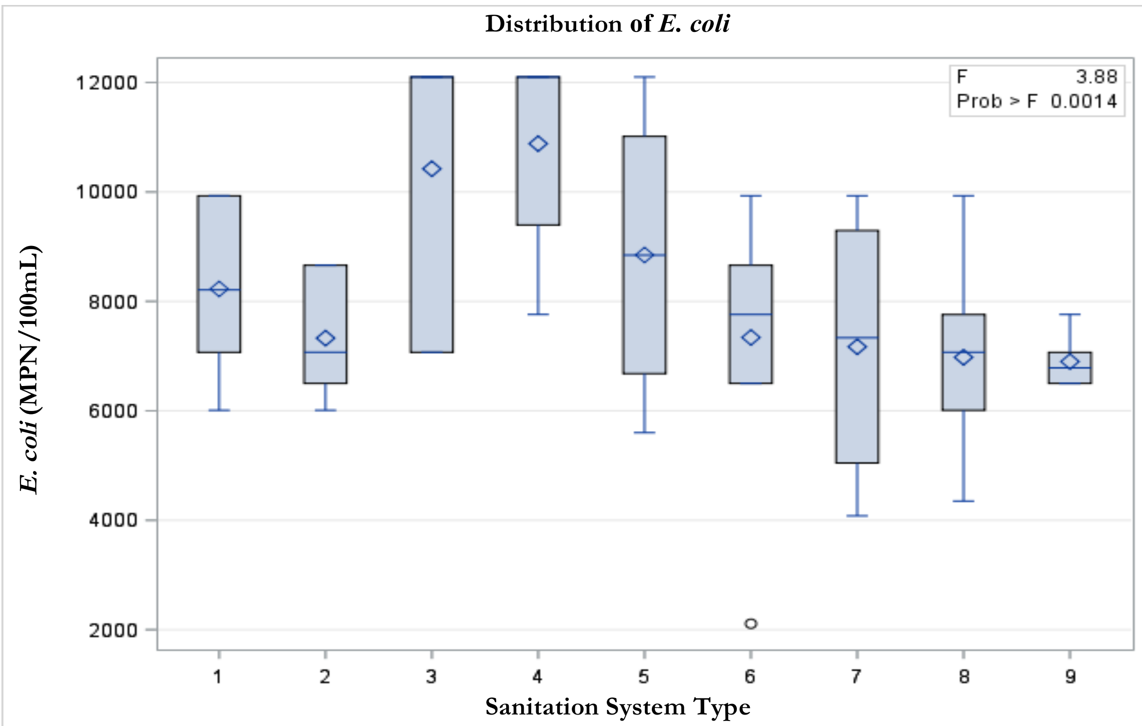


Figure 27. Distribution of E. coli by Sanitation System Type

Across all sanitation system types, the mean pH value was found to be 7.32, where one system had a missing pH value. The maximum value of pH found was 8.31, where the minimum was 6.47. Type 1 systems had the highest mean pH at 7.87, while Type 5 had the lowest mean at 6.92. The distribution of mean pH by Type of sanitation system is shown in Figure 28 below.

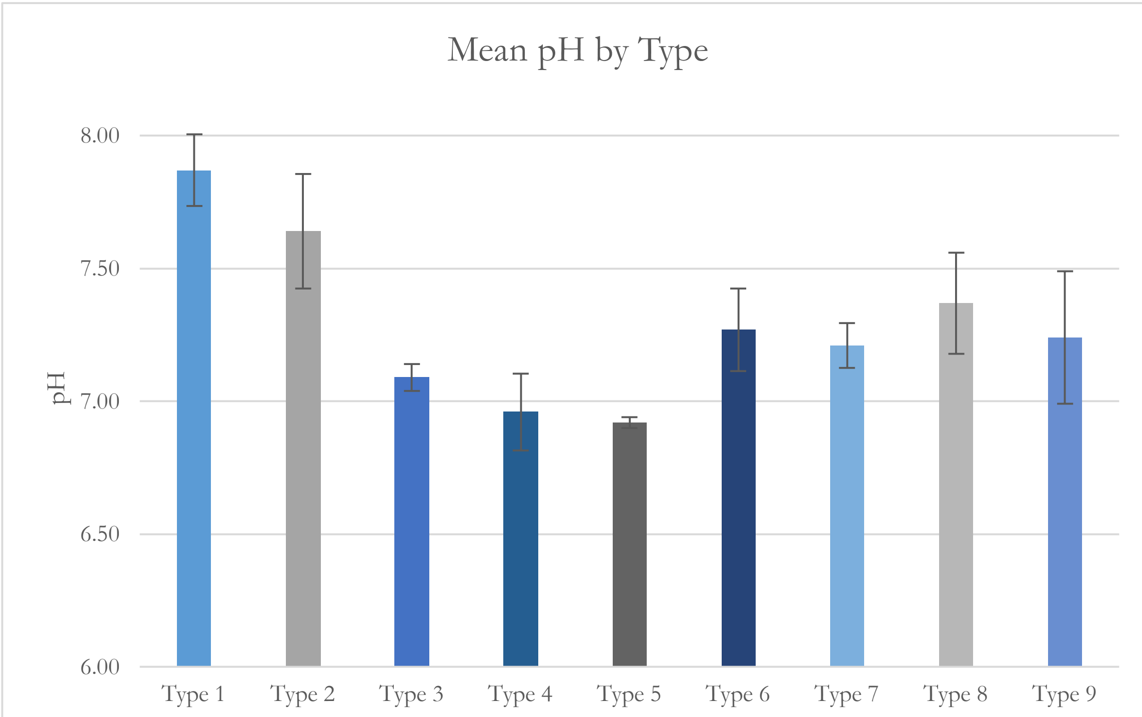


Figure 28. Mean pH by Sanitation System Type (Standard Deviation Error Bars)

When performing the ANOVA in SAS, the distribution of pH was found to not be homogenous in terms of the distribution of variance, using Levene's Test for Homogeneity (Figure 29). In this case, Welch's ANOVA was performed, and the significance of type on the distribution remained statistically significant (F-test p-value = 0.0004, Welch's-test p-value = <0.0001). Based on this analysis, it was shown that 43% of the difference in pH could be explained by sanitation system type (R^2=0.4323, F-test p-value=0.0004). The Games-Howell post hoc test was performed due to the heterogeneity of variance by type using the MIXED command in SAS and performing a Tukey adjustment to allow for differences to be compared across type of sanitation system. Based on this analysis it was found that Type 1 had significantly higher pH when compared to Type 4 (mean difference

(1-4)=0.9121, adjusted p-value=0.0004), and Type 5 (mean difference (1-5)=0.9483, adjusted p-value=0.0085), and Type 2 had significantly higher pH than Type 4 (mean difference (2-4)=0.6787, adjusted p-value=0.0170). See Appendix C Table 18 for full results.

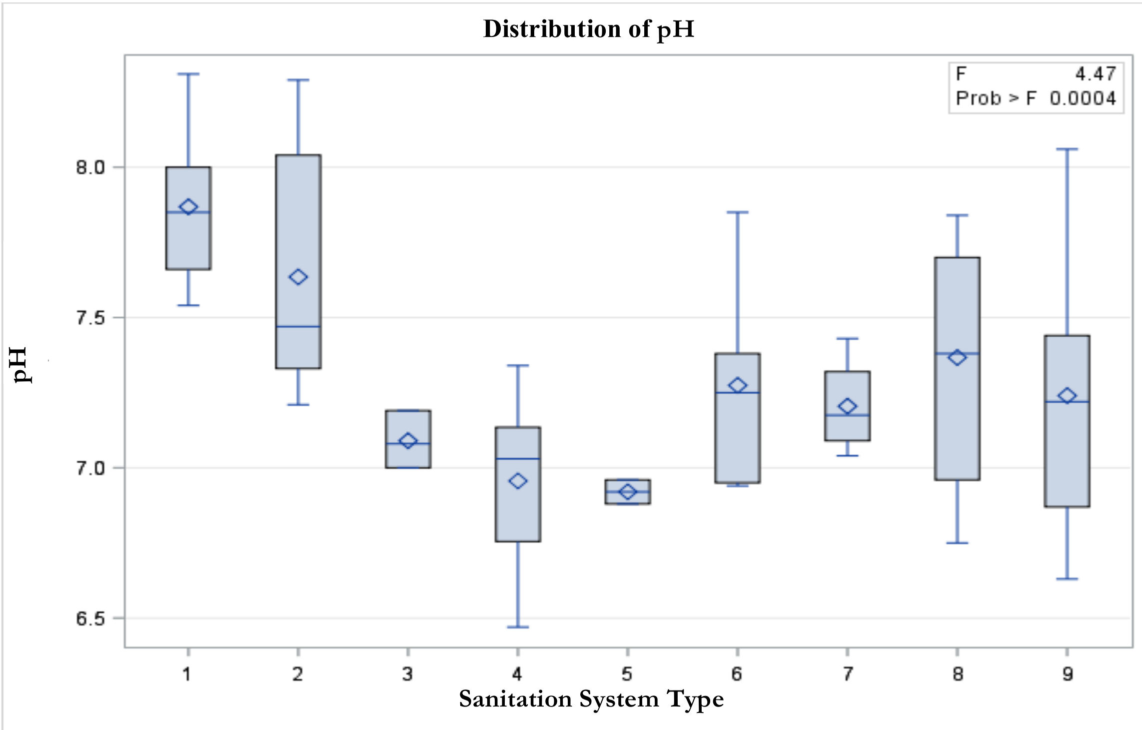


Figure 29. Distribution of pH by Sanitation System Type

Temperature

Mean temperature by aggregate sanitation system type was 27.87˚C, with a maximum value of 32.1˚C and a minimum temperature of 23.4˚C. The distribution of mean temperature by sanitation system type can be seen in Figure 30, which shows that the highest mean temperature was seen in Type 4 at 30.43˚C and the lowest in Type 7 at 25.78˚C.

ANOVA and the Tukey approach show that 56% of the variation of temperature can be explained by the type of sanitation system, with an R^2 value of 0.5561 and an F-test p-value of <0.0001. Individual systems were compared and significant differences were found between many of the sanitation system types, and the results of this analysis can be seen in

Table 19 in Appendix C. It is not likely that the differences in temperature were an effect of the sanitation system design, but rather the area of Indonesia that the system was in use.

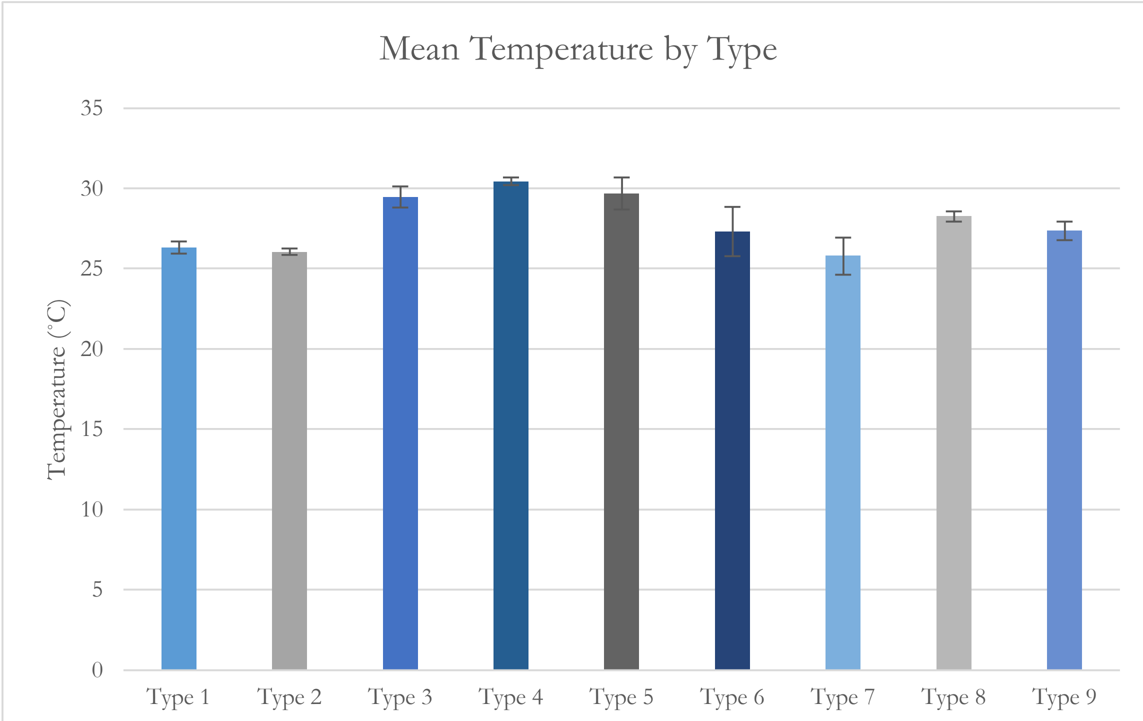


Figure 31. Mean Temperature by Sanitation System Type (Standard Deviation Error Bars)

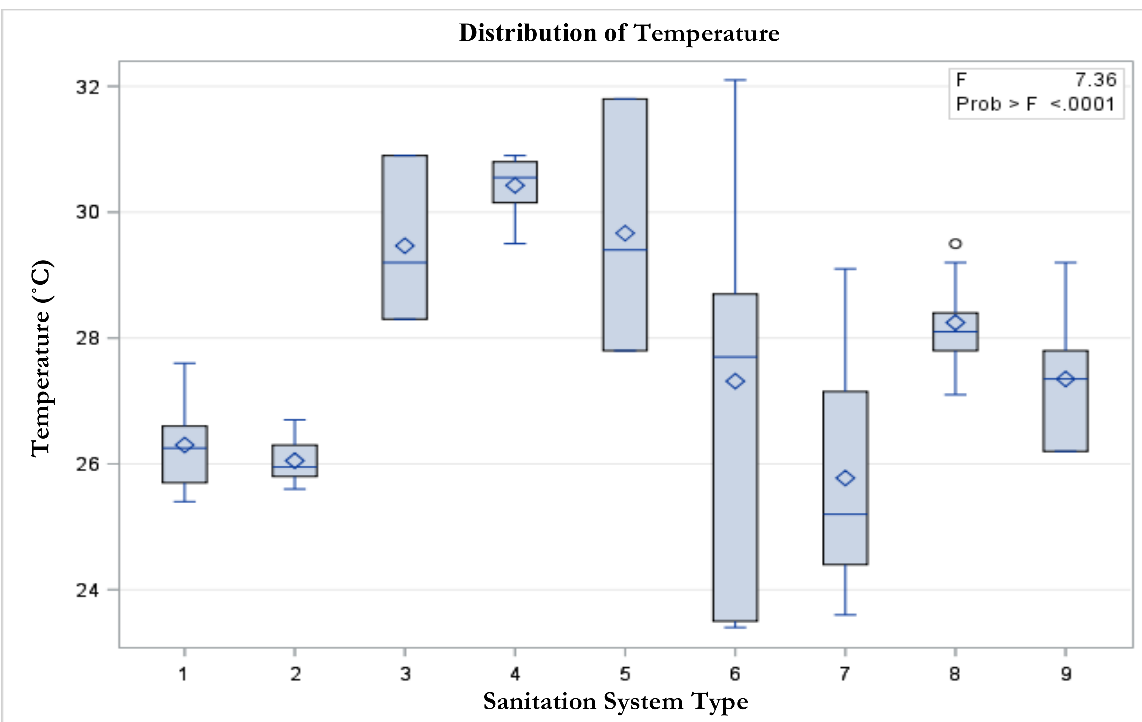


Figure 30. Distribution of Temperature by Sanitation System Type

SLUDGE DEPTH

Out of 57 systems sampled, fecal sludge depth measurements were attained for 41. Mean fecal sludge depth across all types of sanitation systems was 46.18cm, with a maximum of 135.0cm and a minimum of 0.01cm (lower limit of detection). Disaggregated by sanitation system type, Type 8 had the highest mean fecal sludge depth at 84.31cm, where Type 1 had the lowest at 0.01cm (Type 2 had no measurements available). Figure 32 shows the distribution of mean fecal sludge depth by type of sanitation system.

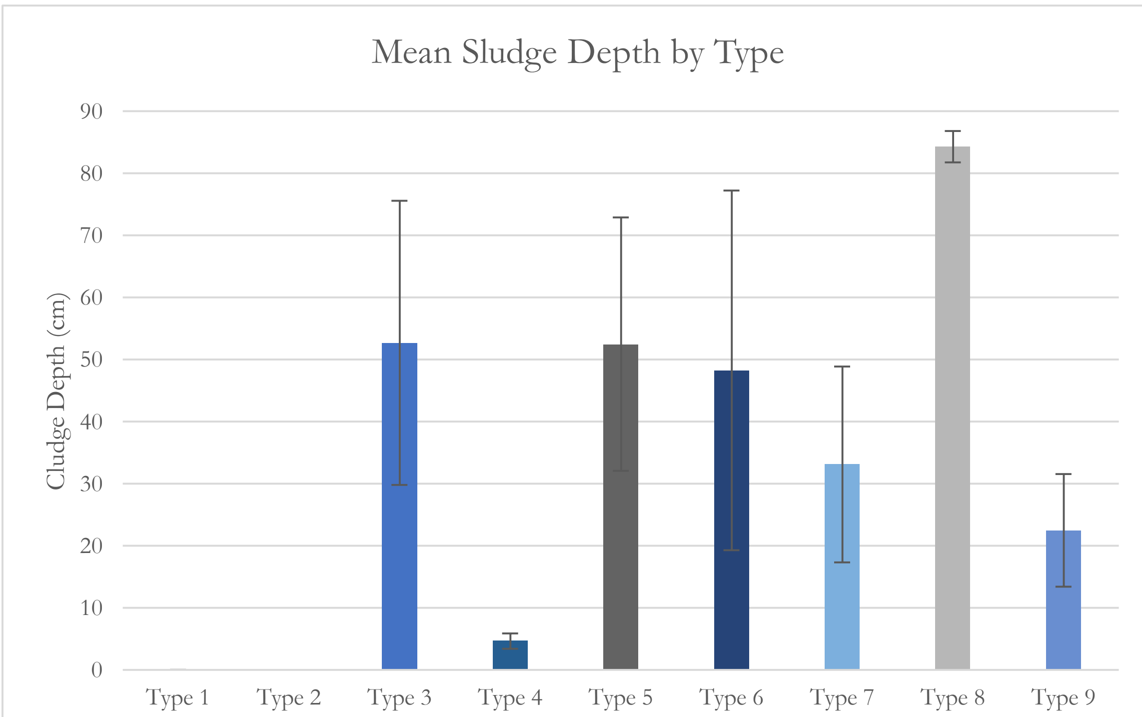


Figure 32. Mean Fecal Sludge Depth by Sanitation System Type (Standard Deviation Error Bars)

Using ANOVA, it was found that 63% of the variance of fecal sludge depth could be explained by sanitation system type (R^2=0.6297, F-test p-value=<0.0001). Figure 33 shows the distribution of sludge depth by individual system types, and after performing Tukey analyses on sludge depth by type, differences in mean sludge depth could be compared across the systems (Table 20 Appendix C). Through this analysis it was found that Type 8 had significantly higher fecal sludge levels than Type 1 (mean difference (8-1)=84.3, 95%CI=(41.65, 126.94)), Type 4 (mean difference (8-4)=79.64, 95%CI=(24.3, 134.98)), Type 7 (mean difference (8-7)=51.18, 95%CI=(1.78, 100.58)), and Type 9 (mean difference (8-9)=61.81, 95%CI=(12.41, 111.21)). See Appendix A Table 11 for full results.

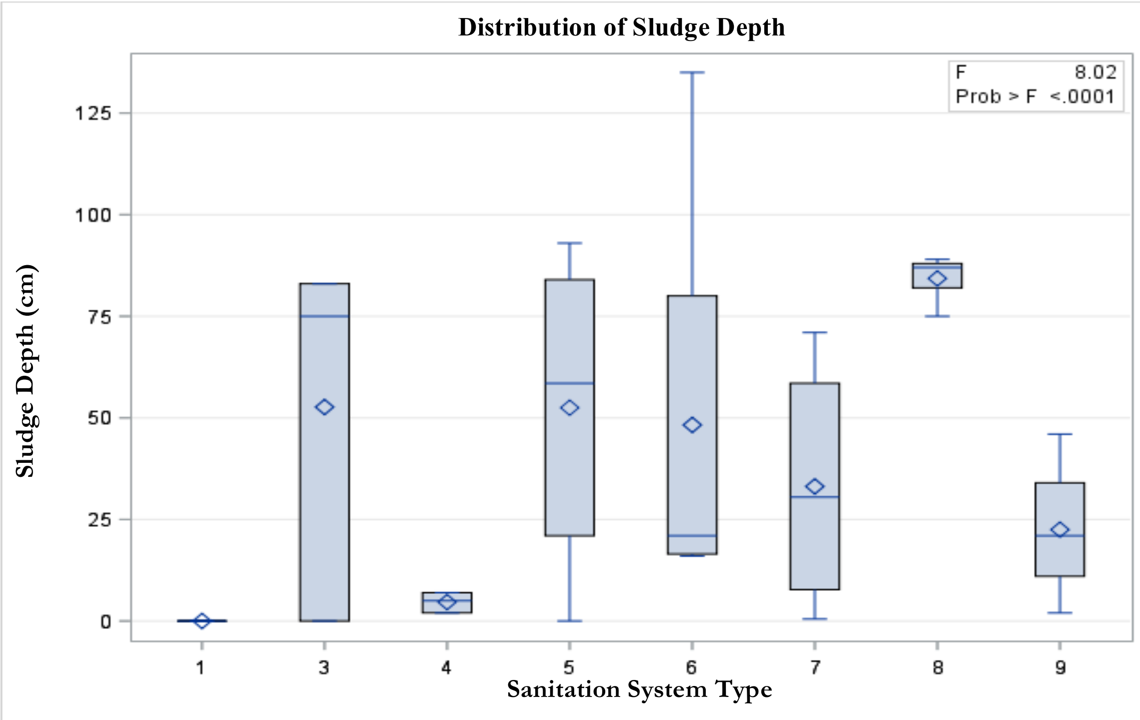


Figure 33. Distribution of Fecal Sludge Depth by Sanitation System Type

Sludge depth relates to the sludge settling volume (SSV) measurements outlined in the methods section. SSV measurements were only available on 10 systems, with ranges from 50mL/30min to 630mL/30min. These measurements did not correlate with sludge depth and due to the small sample size of available measurements, SSV will not be discussed further and warrants further investigation in later studies.

Regression Analyses

Simple Linear Regression

Tables 22 and 23 in Appendix C show the results of the simple linear regressions performed for potential predictor variables and treatment factors. Many factors were significant predictors of treatment variables, and a summary is seen below in Table 10. It is important to note that these models were built with no potential confounders included and was performed to assess the linear relationship between the independent and dependent variable and its ability to predict values based on coefficients.

Table 10. Summary of Simple Linear Regression Analyses

Treatment Factor	Significant Predictors (α = 0.05)
BOD	Type, Temperature, Number of Household Members, COD, TSS, OG
COD	Type, Temperature, Number of Household Members, BOD, pH, TSS, OG
pH	Type, Number of Filters, Temperature, Number of Household Members, COD, TSS
TSS	Type, Volume, BOD, COD, pH, OG
OG	Type, Volume, Temperature, System Emptying, BOD, COD, TSS, *E. coli*
E. coli	Type, Volume, Years Lived in Household, Sludge Accumulation, OG

RIDGE REGRESSION

Table 24 in Appendix C shows the results from the multiple ridge regression analyses performed to evaluate the potential predictors of different treatment factors using multivariate models. Based on these analyses, it was determined that some differences could be attributed to other treatment factors, design and operation factors, and in some instances, both.

In regards to BOD, statistically significant predictors included COD (α<0.0001) and number of household members (α=0.10). For COD, BOD (α<0.0001), OG (α=0.05), number of household members (α=0.05), TSS (α=0.10), *E. coli* (α=0.10), and system emptying (α=0.10) were statistically significant independent variables. TSS had no design and operation factors that were significant predictors, although OG, pH, and BOD were significant (α=0.05, α=0.05, α=0.10, respectively). In regards to OG, significant treatment factors were BOD and COD (both $\alpha<0.0001$), while significant design and operation factors included type of toilet ($\alpha=0.05$), system emptying ($\alpha=0.05$), and volume ($\alpha=0.10$). For pH, statistically significant independent variables included TSS ($\alpha=0.05$), number of filters ($\alpha<0.0001$), number of household members ($\alpha=0.01$), and temperature ($\alpha=0.10$). Moving on to *E. coli*, significant predictors were found to be OG at $\alpha=0.05$, volume of the tank ($\alpha=0.05$), age of the tank ($\alpha=0.05$), and years lived in the household ($\alpha=0.10$). Lastly, an additional analysis was performed to look at the potential predictors of fecal sludge depth for the systems that had available measurements (n=48). This analysis found that significant predictors included the age of tank ($\alpha<0.0001$), type of toilet ($\alpha=0.05$), volume of the tank ($\alpha=0.05$), temperature ($\alpha=0.10$), and OG ($\alpha=0.05$).

Influent and Well Water

Influent samples were collected for only two of the sanitation systems throughout the study. TSS, BOD, COD, OG, surfactants, and chlorine were measured for both samples. Table 11 below shows the individual measures fore each sample.

Table 11. Influent Sample Laboratory Analysis Results

Sample	TSS (mg/L)	BOD (mg/L)	COD (mg/L)	OG (mg/L)	Surfactants (mg/L)	Chlorine (mg/L)
Influent 1	316	397	1210	48	0.87	<0.01
Influent 2	105	91	273	8	0.52	<0.01

As seen, variability was high between the samples, as expected. Due to the nature of the differences, these samples were not included in any analyses, including in calculating percent reductions of certain factors. Influent samples are expected to be highly specific at the household level, so it would be inappropriate to use values from one household to represent another. Two important characteristics that are kept in mind throughout other analyses are surfactant and chlorine levels. Surfactant levels are an important indicator of greywater introduction into the sanitation system and can impact treatment and performance of the system on wastewater treatment. As shown in the two samples, these levels were fairly low and indicate a potential lack of commonality in terms of greywater introduction to sanitation systems. As for chlorine, these results are important for interpreting *E. coli* and total coliform results. Chlorine presence would indicate antimicrobial activities taking place that would impact values of microbial analysis, and due to the results at the lower limit-of-detection, we assume this holds true for other sanitation system samples.

For water samples, collections were performed using shallow wells in three respective study sites (Belawan, Bandung, Jakarta). The results from these analyses can be seen below in Table 12 and include only *E. coli* and total coliform measurements.

Table 12. Well Water Sample Analysis

Sample	Location	*E. coli* (MPN/100mL)	Total Coliforms (MPN/100mL)
Water Sample 1	Belawan	0.5	2420
Water Sample 2	Bandung	0.5	308
Water Sample 3	Jakarta	2	2420

These measurements allow for a background level of *E. coli* and total coliform to be assumed due to environmental factors. Total coliform levels were high for all samples, with those from Belawan and Jakarta seen at the upper limit-of-detection. As for *E. coli*, both Belawan and Bandung had values at the lower limit-of-detection, while the sample from Jakarta found 2 MPN/100mL. Total coliform levels varied, although all were within the regulation limit, although two were less than 600 MPN from exceeding the limit. This has important implications about attributing environmental levels to sanitation systems.

Discussion

The sanitation sector in Indonesia is in the midst of a great boom in innovation and service expansion, resulting in increased involvement and interest in appropriate technologies for wastewater treatment. A crucial factor of this boom is the importance of sustainable, appropriate development as opposed to short-term, unsustainable responses to need. The importance of sanitation for all in Indonesia, especially in the hard to serve difficult environments, cannot be overlooked. However, it is important to ensure adequate use of time and resources to attain long-term change in line with government programs and regulations.

Stakeholder Discussions

Stakeholder discussions resulted in the emergence of three main themes related to sanitation: the general state of sanitation, wastewater quality factor importance, and design factor influence on treatment. An important quote in regards to the state of sanitation in Indonesia was that “the current standard design cannot be feasible...” to meet the needs of the population. This highlighted the importance of investigating alternative technologies to meet the needs of diverse communities and individuals throughout the country. In light of this, a contrasting statement was given by another stakeholder. They said that they “recommend the conventional septic tank – it is easier for the local community to install and manage.” This suggestion highlights the importance of construction, installation, maintenance, and operation needs of any system, which holds true for those investigated in this study. As noted above in the results section, stakeholders regarded varying effluent quality indicators with different levels of importance. This provided an interesting insight into a potential difference between the national regulating agencies and stakeholders/practitioners working in the sector in what they view as important indicators for environmental and public health. As with any country, regulations have to be set to encourage innovation and compliance to protect against adverse outcomes, but they also have to take into account evidence and what is feasible for the sector. The suggested importance of indicators could serve as a discussion point for future sanitation and environment sector regulations to further spur innovative designs to meet the needs of Indonesian households.

The final theme that arose throughout discussions was the varying design factors and their impact on treatment. The majority of insight was gained in relation to anaerobic filters and filter material, as noted in the results section. All stakeholders saw small, filter-based package systems as a solution to meet the needs of Indonesian household waste management and treatment. Many also suggested different filter media based on treatment capabilities, market sustainability, and availability, all of which varied widely. Other factors that were recommended related to specific sanitation systems, and are discussed below or have already been discussed in the results.

Sanitation System Treatment

Treatment of wastewater by on-site decentralized sanitation systems can be affected by many factors, including environmental, design, and operational. Throughout this research, these factors were brought together to determine the influence each might have on the treatment capacity of alternative sanitation systems throughout Indonesia. The statistical analysis performed allowed these influences to be investigated for the systems included in this study.

BOD and COD: BOD and COD were highly correlated (Pearson Correlation Coefficient = 0.9913) and had highly similar characteristics in regards to changing levels with changing factors. Looking at the relationship between these two treatment indicators and the different potential predictors, the type of sanitation system, number of household members, and temperature were significantly associated with both. These finding are consistent with similar studies pertaining to sanitation systems and potential factors influencing treatment. One study by Lew *et al.* in 2011 found that in higher temperatures, metabolic activity was increased which can lead to increased digestion of wastewater components. They noted that lower temperatures were often a limiting factor in reductions of COD due to decreased hydrolysis of suspended organic solids (Lew *et al.,* 2011). A similar study also found that systems operating in higher temperature settings had higher methane output, an indicator of microbial activity in the reduction of COD and BOD (Pussayanavin *et al.*, 2015). Looking at the multivariate regression models, COD is the only treatment indicator that had a significant predictor, being the number of household members. Each one-member increase in the household was predicted to lead to an increase in COD by over 11 mg/L, holding other variables equal. This could be due to increased hydraulic loading rates and exceeding the threshold that the system was designed to handle, which has been seen to lead to decreased levels of wastewater treatment (Morales *et al.,* 2015). These are important operational and environmental factors of the systems investigated and are crucial to consider when designing alternative sanitation systems. Future studies are needed to determine which design factors could be utilized to promote anaerobic digestion, hydrolysis, decreased hydraulic loading rates, and increased hydraulic retention time to ensure adequate reductions seen in both BOD and COD.

TSS: 28% of the variation of TSS could be explained simply by the type of sanitation system ($p = 0.0340$). No significant differences were seen after when comparing mean TSS levels across sanitation systems, although volume of the system was significantly associated with TSS levels when assessed using simple linear regression ($p = 0.0392$). The increased reduction in TSS levels with increasing volume is likely due to increased HRT allowing for more settling of solids, as was seen in a study by Nguyen *et al.* in 2007 where increased HRT was shown to significantly increase the reduction of TSS in laboratory-based systems. It was expected that the number of anaerobic filters would have impacted the TSS levels measured in the effluent, although this was not seen in this study. Previous studies have found a greater increase in the percent reduction of TSS with increasing numbers of anaerobic up-flow filters, although with diminishing returns (Nguyen *et al.*, 2007, Koottatep *et al.*, 2004). One potential explanation could be to the different filter media present in the differing systems as filter media can impact treatment, although filter media use was not available in this project (Feng *et al.*, 2008, Marlisa *et al.*, 2015).

OG: The presence of high levels of oil and grease in wastewater effluent can have detrimental effects on the environment and the sanitation system itself. The presence of oils and grease in wastewater treatment systems can clog drains, pipes, and filters, along with impacting sludge characteristics, all of which can impact other aspects of wastewater treatment (Husein *et al.*, 2014). Oil and grease was found to be significantly impacted by the volume of the system, the act of desludging/emptying the system, and the temperature of the system. Through multivariate regression, both the type of toilet as well as emptying were significant at $\alpha=0.05$ while the volume of the tank was significant at $\alpha=0.10$. Decreased HRT, or increased hydraulic loading, may be an impact of less volume and therefore lead to the higher levels of oil and grease seen in some samples due to less time spend in the treatment system (Morales *et al.*, 2015). Similarly, the type of toilet can have implications on the movement of system contents, importantly oil and grease. Systems lacking a tee inlet and outlet, Types 3 and 5, theoretically have more potential for system mixing and would therefore see greater levels of oil and grease in effluent and these systems had the 2nd and 4th highest levels of OG, respectively. Tee inlets and outlets are important to control inflow velocity and support settling and stabilization of influent components (Bounds, 1997). System emptying and desludging could reduce levels of oil and grease simply by reducing the amount that may build up in the tank, although more research is needed to investigate this relationship. Sanitation system Type 4 had significantly higher levels of oil and grease than many others, and it is important to note that this system is the only one other than the SNI system that is lacking an anaerobic filter. No significant relationship was seen during statistical analysis but a potential reduction could be seen in effluent levels due to adherence of oil and grease compounds to filter media in those systems containing anaerobic filters.

E. coli: *E. coli* is an important indicator of fecal contamination and can indicate potential presence of pathogens that can be used to infer adverse health risks (Gruber et al., 2014; Ashbolt et al., 2001; WHO, 2011). In the analysis of the systems in this study, *E. coli* levels were significantly associated with system volume, sludge accumulation, and the years lived in the household. Through multivariate regression analysis, the age of the tank was also a significant predictor of *E. coli* levels. Sludge accumulation, years lived in the household, and age of the system all share a commonality as indicators of use and age. Hydraulic retention time has been shown in the past to contribute to increase removal of bacteria, including *E. coli* (Stevik *et al.*, 1999, Stevik *et al.*, 2004). These studies by Stevik *et al.* also investigated the role of differential grains in wastewater system filters for the removal of bacteria and saw that filters played an important role in reductions, while a significant relationship was not seen in this study. The age and long-term use of the system, potentially indicated by sludge accumulation, may be associated to a reduction in *E. coli* due to increased colonization of filter media by microorganisms that may outcompete *E. coli* for resources or due to microbial activity in accumulated sludge. This is commonly referred to as the time to reach "steady state" operations where treatment of wastewater reaches an optimal level (Sabry, 2010). Over all systems, a one-year increase of age was predicted to have a decrease in *E. coli* levels by approximately 78 MPN/100mL ($p = 0.0429$). This finding could be partially explained by the older systems having more time to optimize treatment due to internal mechanisms. It is important to consider operation and maintenance factors and the roles they play in treatment performance, and future studies should investigate the role that these might play in reducing *E. coli* levels. Other important confounders to consider would include levels of microbial colonization in filter media, chlorine or other antimicrobial compounds, temperature, pH, organic content, sludge content and activity, as well as others (Carrington, 2001, WHO, 2011). While some confounders were assessed, further studies would benefit from further data collection and analysis on confounders of *E. coli,* as its implications on public health are important factors for assessing sanitation options.

Analysis of design and operational factors and their impact on *E. coli* levels is vital as *E. coli* concentrations have an important implication on a sanitation system's potential impact on public health. Many communities experience regular flooding events that lead to exposure to contaminated water. Other communities rely on surface water for household or recreation use, and contamination with fecal waste can negatively impact individual and community health. While *E. coli* presence is indicative of fecal contamination, it does not always indicate pathogenic risk. For recreational water and contact with water in which a person's head is submerged, one study found that the suggested concentration of *E. coli* where no-observed-adverse-effect occurs is 100 MPN/100mL (Wiedenmann *et al.,* 2006). All of the wastewater samples tested exceeded 100 MPN/100mL, as expected, and the proximity of effluent discharge to water that communities come in contact with on a regular basis could prove harmful to health. In the United States, the Environmental Protection Agency sets recreational water quality criteria for *E. coli* levels for both primary and secondary contact. The most lenient of criteria is for non-contact recreation, where contact with water is expected to be very minimal and risk of ingestion negligible. This is set at 2060 cfu/100mL, well below samples of wastewater effluent from the investigated systems (US EPA, 2012). Considering many environments utilizing these alternative sanitation systems are at considerable risk of ingestion of water impacted by sanitation system effluent, this finding indicates the necessity for further development of protective barriers to block the pathway of contamination of water and contact with or ingestion of that water.

E. coli itself serves as an important indicator organism for other pathogens and has been shown to be significantly associated with diarrheal outcomes (Gruber *et al.*, 2014). Survival of *E. coli* and other potentially harmful microorganisms in the environment can vary and are essential to consider when assessing public health risk with inadequate sanitation. Environment can refer to soil, water, surfaces, or other secondary habitats, and declines can occur due to factors. Temperature, pH, water availability, nutrient availability, and biotic competition all impact survival of *E. coli*, and are important for consideration of microbial risk in the environment (Van Elsas *et al.*, 2011).

In regards to environmental contamination, two well water samples had values for *E. coli* that were at the lower limit of detection, while one sample was found to have 2

MPN/100mL. This sample was taken from a shallow well in Jakarta, a very densely populated area. This finding could serve as an indicator of fecal contamination of the well due to improper functioning of sanitation systems, although the source cannot be determined.

pH: pH is an important factor in wastewater treatment as it impacts microorganism activity and other treatment pathways, including sludge digestion. Optimal pH levels for wastewater treatment are 6.5 – 7.5, with a wider range still acceptable but with decreased treatment levels (Stevik *et al.*, 2004). All samples in this study were within the Ministry of Environment regulation levels of 6-9, and even though all were within limits, some differences across systems were seen. The number of filters, number of household members, and temperature of each system were found to be significantly associated with pH in both simple and multivariate regression models. The number of filters in the system was shown to be associated with the largest effect, with an additional one filter associated with an increase in pH by 0.144 ($p = <0.0001$). These findings are consistent with previous studies that investigated the impact of sanitation system design on treatment (Stevik *et al.*, 2004, Parkin and Owen, 1986). A study by Parkin and Owen found that changes in organic loading, changes in hydraulic characteristics, and temperature changes all have the potential to impact pH. An increase in temperature and organic loading were associated with a lower pH, where changes in hydraulic characteristics were more nuanced in response (Parkin and Owen, 1986). These results have important implications as to the design of systems to combat excessive organic loading in regards to increased household usage as well as with the number of filters to potentially increase pH.

Sludge Depth: Fecal sludge is a natural process in most sanitation systems and is especially important in small systems like those included in this study. Through multivariate regression, statistically significant predictors of sludge depth include temperature ($p=0.10$) and volume of the system, type of toilet, and the age of the system. Age of the sanitation system is an important factor in sludge depth due to the accumulation over time that will require desludging. Many of the systems identified had never been desludged even though many of them had been designed with regular desludging expected. Volume of the system is also related as a larger volume could allow for increased hydraulic retention time and increased settling potential (Nguyen *et al.*, 2007). Type of toilet importantly relates to the type of input and potential for mixing of system contents resulting in different levels of sludge settling (Bounds, 1997). Some systems had no values available for sludge accumulation and sludge depth simply due to inaccessible chambers of the sanitation system. It is important for future studies to look at a larger number of systems with accessible inner chambers to determine impacts on sludge accumulation so national desludging policies can be incorporated in designs.

Performance: Overall performance of different sanitation system types was highly variable although no significant differences were found in the mean performance when comparing sanitation system types. This measurement takes into account 6 factors included in government regulations: BOD, COD, TSS, pH, OG, and total coliforms. The best performing system was Type 2, the 1 filter cylindrical septic tank. This system had a volume of $1.0m^3$, one filter unit comprised of what was designed to be PVC filter media, and a tee inlet. While this system did not have the lowest values for each treatment indicator, it did have the best overall performance after equally weighting each indicator. As discussed above, certain factors might have played a role in the increased treatment and values of wastewater indicators seen in the effluent. The level of overall performance could have resulted from lower COD and BOD levels due to the low mean number of household users, low TSS due to increased HRT, low OG levels due to the system that was emptied as well as the tee inlet design, equal total coliforms to the other systems, and optimal pH due to proper operating conditions. The worst performing system was Type 3, the 2 filter floating septic tank. One potentially important characteristic of Type 3 is the direct inflow of wastewater from a pour-flush gooseneck squat plate to the settling chamber of the septic tank. This system also has a small volume of $0.60m^3$ which could contribute to decreased treatment when compared to those of larger volumes. This system also had a mean household member size of 5.3, higher than over half of the other system types.

LIMITATIONS

One major limitation of this study is the small sample size and sampling strategy of systems included in the analysis. Some sanitation system types had very few samples included in analysis which may not accurately represent the treatment capacity of the system. Small sample sizes allow for greater influence of outliers on analysis which may account for some of the differences seen in the study. The sampling strategy also could impact results and their interpretation, as only currently functioning and in-use systems with accessible effluent discharge outlets were included in the study. These systems could significantly differ from other inaccessible systems and might not be a representative sample, and sustainability is also an important aspect of sanitation options. Many systems were broken, discarded, or unused, which is important to consider alongside treatment results. The use of grab samples is also a limitation, as variability could be present across sampling times and dilutions of samples due to cleansing water used for collection.

Another limitation of the study is that some system characteristics had to be estimated based on stakeholder discussions and could not be confirmed during field analysis. Factors such as filter media, volume, and simply put, the inner mechanisms of some systems could not be observed and verified due to the construction of the systems. Many types were sealed fiberglass or sealed concrete tanks which could not be opened to observe the inner construction and design of the system, so analysis could only be performed primarily on the "as designed" inference rather than "as installed". This study also relied on a convenience sample of systems based on those known by stakeholders and community leaders that were interviewed during the project. These were primarily the developers, implementers, and community partners associated with each system and therefore could have resulted in biased inclusion of certain systems. Along with this, systems were only included in the study if they were in good working order and still in use. Many systems were either broken, not maintained, or not used, all of which are critical outcomes to consider when assessing the sustainability and appropriateness of sanitation systems (see Figures section).

This study also aimed to assess potential confounders of sanitation system treatment, but not all potential confounders were included. Sanitation system performance and wastewater effluent quality indicators are highly variable and dependent on many design, operational, and environmental factors. Factors such as number of household members, temperature, volume, and others included aimed to address some of the confounding issues, but others such as actual use, amount of cleansing water used, hydraulic retention time, frequency of use, greywater introduction, and many more can impact indicators. This is an important limitation of this study and should be considered when interpreting results.

Conclusions

Indonesia's plan to increase reach universal access to sanitation by 2019 is an ambitious goal but is one that realizes the urgency needed to provide the human right to sanitation. For the time, money, and resources invested in this and other endeavors to be effective, performance and sustainability of sanitation goods and services need to be considered. Throughout Indonesia, innovative solutions to sanitation challenges have been developed, but little research has been done to look into the availability and functioning of these systems.

The intent of this study was to assess the design and availability of alternative sanitation systems throughout Indonesia and to examine how wastewater effluent quality differed across the designs. Keeping in mind the small sample size for each design and other noted limitations, some broad conclusions can be drawn from the study. National and local stakeholders are continuously engaged and in support of innovation in the sanitation sector and should be an essential collaborator of future sanitation initiatives. Many alternative on-site sanitation system designs have been developed by public, private, and academic institutions throughout the country, each of which was designed to meet the national regulations on wastewater effluent quality and to meet the needs of the diverse population of Indonesia. Although none of the systems investigated adhered to all aspects of the regulations, certain conclusions can be made from the treatment each system was capable of, as determined by laboratory analysis.

In regards to design factors, system volume, number of filters, and type of inflow were found to be significantly associated with multiple treatment indicators. Operational factors that significantly impacted treatment include the number of household members, emptying and desludging of the system, years lived in the household, and the age of the system. Lastly, the environmental factor of temperature was found to be significantly associated with multiple wastewater effluent quality indicators. These findings are consistent with literature pertaining to principles of wastewater treatment and suggest that holistic design approaches to addressing on-site sanitation needs in Indonesia are essential to adequately handle household excreta.

This project was an opportunity to assess on-site sanitation availability and treatment efficacy throughout Indonesia with the help and guidance and assistance of public and private sector stakeholders as well as community members using the non-standard design sanitation systems. This allowed for a portfolio of current designs to be generated including both their areas of implementation and effluent quality values, both of which are essential to determine potential areas for innovation to meet the sanitation needs of the nation. The results of this project are intended to help inform future sanitation investments at the national and household level and to promote solutions that protect the health of populations and the environment throughout Indonesia.

Recommendations for Future Studies

To further advance the knowledge base available for appropriate investment in sanitation in Indonesia and similar environments, continued assessments of both available system designs and their treatment capabilities should be performed. This study relied on very small sample sizes both in terms of system types as well as the number of individual systems, and future studies could benefit from more robust analyses by increasing sample sizes and utilizing different validated regression models. It is also recommended that further studies attempt to attain detailed construction and installation characteristics to be able to evaluate system specific variables, such as the type of media filter present and the volume as-constructed. One final suggestion would be to include analyses of cost, operation, maintenance, and sustainability when assessing on-site sanitation systems. These are all important factors in the feasibility of any sanitation system, and as was observed in this study, sustainability can be an issue in regards to broken or unused systems.

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FIGURES

As seen in the top and bottom left, desludging services were present in many of the study sites, although the large desludging pump truck likely lacks the ability to reach households in dense areas and housing over water. The top and bottom right figures show advertisements for desludging services in Jakarta, highlighting the potential for household awareness of the need for and service options for desludging.

Environmental factors in Medan study site. Many households were located on coastal areas, built over water, and/or impacted by daily tidal flooding. These environmental characteristics are important when considering designs of sanitation systems, and contributed to many of the broken and unused systems seen throughout the study site.

Broken and discarded

Used for housing support

No longer in use

Used for storage

In use and leaking

Inaccessible

Broken and exposed

These are examples of issues encountered in regards to the sustainability and use of the systems in the study.

APPENDIX A – HOUSEHOLD SURVEY

Household ID (Province-City-Date-HH#):				
GPS Coordinates (Latitude, Longitude):				

A	**General**				
A1	Date of Survey		A2	Start Time of Survey	
A3	Province				
A4	City				
A5	District				
A6	Address				
A7	Head of Household	Head of Household .... 1 Spouse of Head of Household .... 2 Other (Specify) 9			
A8	Gender	Male .... 1 Female .... 2 Other (Specify) 9			
A9	Age	Age			

B	**Socioeconomic / Demographic**	
B1	Type of Household	Permanent (solid, brick, concrete) .... 1 Semi-Permanent (wood, steel sheets, etc.) .... 2 Apartment/Flat .... 3 Other (Specify) 9
B2	Housing Status	Owned .... 1 Rented .... 2 Shared .... 3 Other (Specify) .... 9 Don't Know 0
B3	Household Location	Urban .... 1 Peri-Urban .... 2 Rural 3

		Rural (agricultural) .... 4 Over Water .... 5 Tidal Area .... 6 Swamp/Marsh .... 7 Other (Specify) 9
B4a	*Observation* Easily Accessible by Sludge Removal Truck/Cart	Yes .... 1 No .... 2 Uncertain 9
B4b	*Measurement* Distance to the nearest access for emptying truck/pump	Distance (m)....................
B5	Number of Household Members	# who sleep in household regularly ....
B6	Number of years lived in household	# years ....
B7	Employment of head of household	Agricultural .... 1 Factory/Industry Worker .... 2 Livestock/Fishery .... 3 Army/Police/Civil Servant.................... 4 Private Employee .... 5 Business Owner .... 6 Other (Specify) 9
B8	HH Income	Total (IDR/month) = ... Don't Know 0
B9	Main Drinking Water Source	Piped .... 1 Shallow Well .... 2 Drilled Well .... 3 Surface Water .... 4 Bottled Water .... 5 Truck/Tanker Water.................... 6 Rain Water .... 7 Spring Water .... 8 Other (Specify) .... 9 Don't Know 0
B10	Main Household Water Source (not drinking)	Piped .... 1 Shallow Well .... 2 Drilled Well .... 3 Surface Water 4

		Bottled Water .... 5 Truck Water .... 6 Rain Water .... 7 Spring Water .... 8 Other (Specify) .... 9 Don't Know 0
B11	Household Size (House Floor Area)	Size (m^2) .... Don't Know 0
B12	**Observation and Measurement** Available plot area for sanitation system	Area (Plot Size m^2) .... Front Yard .... 1 Back Yard .... 2 Under Terrace/Closet .... 3 Under House (Rumah Panggung) .... 4 Attached to House (Rumah Apung) .... 5 Other (Specify) .... 9 Other comments:
B13	Other Household Comments	

C	Sanitation Information	
C1	Where do most members of your household go to the toilet (defecate)? **Select all that apply*	Household Toilet.......... 1 Neighbor/Family Toilet .... 2 Communal Toilet .... 3 River, drain, water, bush, bag .... 4 Other (Specify) .... 9 Don't Know 0
C2	Type of toilet	Goose-Neck Cistern Flush .... 1 Goose-Neck Pour Flush .... 2 Squat w/o Goose-Neck .... 3 Container-Based/Bucket .... 4 Informal/hanging toilet .... 5 Other (Specify) .... 9 Don't Know 0
C3	Discharge from toilet goes to…	Tank (septic tank) .... 1 Tank (other) .... 2 Pit on-site (cubluks) .... 3 Piped to Drain 4

		Piped to Waterway .... 5 Directly to River/Waterway .... 6 Sewer .... 7 Other (Specify) .... 9 Don't Know 0
C4	What other waste is disposed of in the toilet?	Cleansing Water .... 1 Kitchen/Household Water and Waste .... 2 Dry Cleansing Material (toilet paper, paper) .... 3 Menstrual Hygiene Materials .... 4 Animal Waste .... 5 Childs Feces/Diapers .... 6 Solid Waste/Trash .... 7 Other (Specify) 9
C5	If C3=yes, location of the tank	Outside the House (yard) .... 1 Outside the House (off property) .... 2 Under the House (accessible) .... 3 Under the House (inaccessible) .... 4 In/On River .... 5 Attached to Housing Structure (stilts, floatation tanks, etc.) .... 6 Other (Specify) .... 9 Don't Know 0
C6	Can the tank be observed? **if yes, observe tank to answer C7-C12*	Yes .... 1 No .... 2 Other (Specify) 9
C7	Type of system	Septic Tank (1 chamber) .... 1 Septic Tank (>1 chamber) .... 2 Other (Specify) .... 9 Don't Know .... 0 ***Name of System(product name, project name, etc.):***
C8	Material of tank	Plastic .... 1 Fiberglass .... 2 Concrete .... 3 Brick or Blockwork........ 4 Partial brick/cement/plaster .... 5 Brick and plaster/cement .... 6 Other (Specify) .... 9 Don't Know 0
C9	Above/below ground and water	Above Ground .... 1 Partially Below Ground .... 2 Below Ground .... 3 Above Water (Not Touching) 4

		Above Water (Floating) .... 5 Partially Submerged .... 6 Fully Underwater .... 7 Other (Specify) .... 9 Don't Know 0
C10	Type of seal	Plastered or Cemented or Under house (not able to open) .... 1 Lid (tight seal) .... 2 Lid (loose seal) .... 3 Open Lid .... 4 Other (Specify) .... 9 Don't Know 0
C11	Location of discharge	Pipe to Leach Field .... 1 Pipe to Drain .... 2 Pipe to river/water .... 3 No Pipe .... 4 Soak Pit .... 5 Open-Bottomed Tank .... 6 Other (Specify) .... 9 Don't Know 0
C12	Tank dimensions	Length (m) .... Width (m) .... Diameter (m) .... Depth (if buried) (m) .... Don't Know/Inaccessible 0
C13	Age of tank	Years Old ....
C14	Builder/Installer of System	Household (Independent) .... 1 Household (Assistance provided) .... 2 Hired Mason .... 3 Tank Provider/Company .... 4 Sanitation Program .... 5 Other (Specify) .... 9 Don't Know 0
C15	Has the system needed maintenance or stopped working/overflowed? **other than emptying*	Yes .... 1 No .... 2 Don't Know 0

C16	If C15=yes, what was the nature of the problem?	Regular Scheduled Maintenance .... 1 Government/Organization Ordered Maintenance .... 2 Blocked Pipe .... 3 Smell Problem .... 4 Tank/Toilet Overflow .... 5 Tank Damage .... 6 Pipe Damage .... 7 Other (Specify) 9
C17	If C15=yes, who performed the maintenance?	Household (Independent) .... 1 Household (Assistance provided) .... 2 Hired Mason .... 3 Tank Provider/Company .... 4 Sanitation Program .... 5 Other (Specify) .... 9 Don't Know 0
C18	If C15=yes, how often does it need maintenance?	Once .... 1 Occasionally .... 2 Regularly .... 3 Other (Specify) .... 9 Don't Know 0
C19	Has the system needed emptying?	Yes .... 1 No .... 2 Other (Specify) .... 9 Don't Know 0
C20	If C18=yes, when was it emptied?	<3 months ago .... 1 3-6 months ago .... 2 6 months-1 year ago .... 3 1-3 years ago .... 4 3-5 years ago .... 5 > 5 years ago .... 6 Other (Specify) .... 9 Don't Know 0
C21	If C18=yes, why was it emptied?	Tank Full .... 1 Scheduled Emptying .... 2 Emptied During Maintenance .... 3 Instructed to Empty (government, program) .... 4 Other (Specify) .... 5 Don't Know 6
C22	If C18=yes, who emptied it?	Self/Household .... 1 Neighbor/Community Member/Friend .... 2 Private Company .... 3 Government........ 4

		NGO Program .... 5 Other (Specify) .... 9 Don't Know 0
C23	If C18=yes, how was it emptied?	Vacuum Pump .... 1 Shovel/Bucket .... 2 Manual Pump .... 3 Flushed into Environment .... 4 Other (Specify) .... 5 Don't Know 0
C24	If C18=yes, how much did it cost?	IDR........ Other (Specify) .... 9 Don't Know 0
C25	Jika C19=ya, How often does it get/need emptied?	More than once a year .... 1 Once a year .... 2 Once every two years .... 3 Once every 3 years .... 4 Once every 4 years .... 5 Once every 5 years .... 6 Other (Specify) .... 9 Don't Know 0
C26	Other comments about sanitation system	

D	Technical	
D1	How much did the system cost?	Product/Tank (IDR) .... Installation (IDR) .... Other (Specify) (IDR) 9
		Total (IDR) ....
		Don't Know 0
D2	Have any modifications been made to the system?	Yes .... 1 No .... 2 Other (Specify) .... 9 Don't Know 0
D3	If D2=yes, what modifications have been made?	Inlet/Outlet Piping .... 1 Tank Chamber – Baffle .... 2 Tank Chamber – Media Filter .... 3 Starter Material Added (MBIO, activated sludge, etc.) 4

		Effluent/Outflow Filter .... 5 Other (Specify) .... 9 Don't Know 0
D4	If D2=yes, who made the modifications?	Household (Independent) .... 1 Household (Assistance provided) .... 2 Hired Mason .... 3 Tank Provider/Company .... 4 Government Sanitation Program .... 5 NGO Sanitation Program .... 6 Other (Specify) .... 9 Don't Know 0
D5	If D2=no, has anyone suggested/informed you to modify your sanitation system?	Yes .... 1 No .... 2 Other (Specify)........ 9 Don't Know 0
D6	If D5=yes, why did they suggest or tell you to modify your system?	Record Response ....
D7	Other technical design/modification comments about the system?	

Appendix B – Observation Tool

Household ID (City-System--HH#): Sanitation System ID: Date & Time:					
E	**Measurements**				
E1	Scum Depth (cm)				
E2	Sludge Depth (cm)				
E3	Temperature of Tank (˚C)				
F	**Technical Observation**	√			√ / #
F1	Sealed Lid		F11	Visible Cracks	
F2	Vent Pipe		F12	# of Chambers	
F3	T-Inlet		F13	# of Baffles (hanging or full)	
F4	T-Outlet		F14	Shallow Well < 10 m from Tank	
F5	Filter Media (in tank)		F15	If F14=yes, Distance from Tank to Well (m)	
F6	Infiltration Field		F16	Overflow Pipe	
F7	Anaerobic		F17	Outflow Pipe Above Inflow Pipe	
F8	Aerobic (oxygenated)		F18	Inlet Chamber (pre-septic tank chamber)	
F9	Effluent Filter		F19	Effluent Outflow Below Water Level	
F10	Multiple Tanks (separate)		F20	Grease Trap or Control Box Before Tank	
G	**Environmental Conditions**	√			√
G1	Dense Urban		G6	Marsh/Swamp	
G2	Dense Rural		G7	Coastal Area	
G3	On-River		G8	Floodplain	
G4	Riverbank		G9	Housing over Water	
G5	Tidal Area		G10	High Groundwater Table	

Appendix C – Statistical Analysis

Table 13. ANOVA of COD (Difference Between Means mg/L (95%CI))

	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9
Type 1	-99.7 (-834.4 - 635.1)	905.3 * (5.4 - 1805.2)	324.1 (-363.2 - 1011.4)	161.8 (-659.7 - 983.2)	138 (-570.0 - 846.0)	167.8 (-653.7 - 989.2)	-40.4 (-668.5 - 587.7)	-201.8 (-936.6 - 532.9)
Type 2		1005.0 * (105.1 - 1904.9)	423.8 (-263.5 - 1111.1)	261.4 (-560.1 - 1082.9)	237.7 (-470.4 - 945.7)	267.4 (-554.1 - 1088.9)	59.3 (-568.8 - 687.4)	-102.2 (-836.9 - 632.6)
Type 3			-581.2 (-1442.8 - 280.4)	-743.6 (-1715.6 - 228.4)	-767.3 (-1645.5 - 110.9)	-737.6 (-1709.6 - 234.4)	-945.7 * (-1760.9 - -130.6)	-1107.2 * (-2007.1 - -207.3)
Type 4				-162.4 (-941.7 - 617.0)	-186.1 (-844.8 - 472.5)	-156.4 (-935.7 - 623)	-364.5 (-936.4 - 207.4)	-526 (-1213.3 - 161.3)
Type 5					-23.8 (-821.4 - 773.9)	6.0 (-893.9 - 905.9)	-202.1 (-929.8 - 525.5)	-363.6 (-1185.1 - 457.9)
Type 6						29.8 (-767.9 - 827.4)	-178.4 (-775 - 418.2)	-339.8 (-1047.9 - 368.2)
Type 7							-208.1 (-935.8 - 519.5)	-369.6 (-1191.1 - 451.9)
Type 8								-161.4 (-789.6 - 466.7)
Type 9								

* indicates statistical significance at alpha = 0.05

Table 14. ANOVA of BOD (Difference Between Means mg/L (95%CI))

	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9
Type 1	-34.83 (-265.81 - 196.14)	308.33 * (25.45 - 591.22)	84.58 (131.47 - 300.64)	43.33 (214.90 - 301.57)	30.48 (-192.10 - 253.05)	40.83 (217.40 - 299.07)	-5.21 (-202.65 - 192.24)	-70.67 (-301.64 - 160.31)
	Type 2	343.17 (60.28 - 626.05)	119.42 (96.64 - 335.47)	78.17 (180.07 - 336.40)	65.31 (-157.26 - 287.88)	75.67 (-182.57 - 333.90)	29.63 (-167.82 - 227.08)	-35.83 (-266.81 - 195.14)
		Type 3	-223.75 (-494.59 - 47.09)	265.00 (570.55 - 40.55)	-277.86 * (-553.93 - -1.79)	267.50 (573.05 - 38.05)	-313.54 * (-569.78 - -57.29)	-379.00 * (-661.89 - -96.11)
			Type 4	41.25 (286.24 - 203.74)	-54.11 (-261.16 - 152.94)	43.75 (288.74 - 201.24)	-89.79 (-269.56 - 89.98)	-155.25 (-371.31 - 60.81)
				Type 5	-12.86 (-263.61 - 237.89)	2.50 (285.39 - 280.39)	-48.54 (-277.28 - 180.21)	-114.00 (-372.24 - 114.24)
					Type 6	10.36 (240.39 - 261.11)	-35.68 (-223.23 - 151.87)	-101.14 (-323.72 - 121.43)
						Type 7	-46.04 (-274.78 - 182.71)	-111.50 (-369.74 - 146.74)
							Type 8	-65.46 (-262.91 - 131.99)
								Type 9

* indicates statistical significance at alpha = 0.05

Table 15. ANOVA of TSS (Difference Between Means mg/L (95%CI))

	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9
Type 1	18.33 (-349.18 - 385.84)	351.83 (-98.27 - 801.94)	226.96 (-116.82 - 570.73)	147.83 (-263.06 - 558.72)	13.69 (-340.45 - 367.83)	319.08 (-91.81 - 729.97)	51.37 (-262.79 - 365.54)	55.5 (-312.01 - 423.01)
Type 2		333.5 (-116.61 - 783.61)	208.63 (-135.15 - 552.4)	129.5 (-281.39 - 540.39)	-4.64 (-358.78 - 349.5)	300.75 (-110.14 - 711.64)	33.04 (-281.13 - 347.21)	37.17 (-330.34 - 404.68)
Type 3			-124.88 (-555.82 - 306.07)	-204.00 (-690.17 - 282.17)	-338.14 (-777.4 - 101.12)	-32.75 (-518.92 - 453.42)	-300.46 (-708.18 - 107.25)	-296.33 (-746.44 - 153.77)
Type 4				-79.13 (-468.93 - 310.68)	-213.27 (-542.71 - 116.18)	92.13 (-297.68 - 481.93)	-175.59 (-461.62 - 110.45)	-171.46 (-515.23 - 172.32)
Type 5					-134.14 (-533.12 - 264.83)	171.25 (-278.86 - 621.36)	-96.46 (-460.42 - 267.5)	-92.33 (-503.22 - 318.56)
Type 6						305.39 (-93.58 - 704.37)	37.68 (-260.74 - 336.1)	41.81 (-312.33 - 395.95)
Type 7							-267.71 (-631.67 - 96.25)	-263.58 (-674.47 - 147.31)
Type 8								4.13 (-310.04 - 318.29)
Type 9								

* indicates statistical significance at alpha = 0.05

Table 16. ANOVA of Oil and Grease (Difference Between Means mg/L (95%CI))

	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9
Type 1	-16.67 (-70.3 - 103.63)	36.33 (-70.18 - 142.84)	68.92 (-12.43 - 150.27)	-11.08 (-108.31 - 86.15)	-16.62 (-100.42 - 67.18)	-20.33 (-117.56 - 76.9)	-16.26 (-90.6 - 58.09)	-22.67 (-109.63 - 64.3)
Type 2		53.00 (-53.51 - 159.51)	85.58 * (4.23 - 166.93)	5.58 (-91.65 - 102.81)	0.05 (-83.75 - 83.85)	-3.67 (-100.9 - 93.56)	0.41 (-73.93 - 74.75)	-6.00 (-92.97 - 80.97)
Type 3			32.58 (-69.39 - 134.56)	-47.42 (-162.46 - 67.63)	-52.95 (-156.9 - 50.99)	-56.67 (-171.71 - 58.38)	-52.59 (-149.07 - 43.89)	-59.00 (-165.51 - 47.51)
Type 4				-80.00 (-172.24 - 12.24)	-85.54 * (-163.49 - -7.58)	-89.25 (-181.49 - 2.99)	-85.17 * (-152.86 - -17.49)	-91.58 * (-172.93 - -10.23)
Type 5					-5.54 (-99.95 - 88.88)	-9.25 (-115.76 - 97.26)	-5.17 (-91.3 - 80.95)	-11.58 (-108.81 - 85.65)
Type 6						-3.71 (-98.13 - 90.7)	0.36 (-70.25 - 70.98)	-6.05 (-89.85 - 77.75)
Type 7							4.08 (-82.05 - 90.2)	-2.33 (-99.56 - 94.9)
Type 8								-6.41 (-80.75 - 67.93)
Type 9								

* indicates statistical significance at alpha = 0.05

Table 17. ANOVA of E. coli (Tukey adjustment for heterogeneity)

Comparison	Difference Between Means	Standard Error	t Value	Pr > |t|	Adjusted p-value
Type 1 vs 2	898.33	1118.88	0.8	0.426	0.9963
Type 1 vs 3	-2196.67	1370.34	-1.6	0.1155	0.7984
Type 1 vs 4	-2654.58	1046.61	-2.54	0.0145	0.241
Type 1 vs 5	-620.83	1250.94	-0.5	0.622	0.9999
Type 1 vs 6	886.67	1078.18	0.82	0.4149	0.9956
Type 1 vs 7	1056.67	1250.94	0.84	0.4025	0.9947
Type 1 vs 8	1250.51	956.47	1.31	0.1973	0.9242
Type 1 vs 9	1326.67	1118.88	1.19	0.2416	0.9557
Type 2 vs 3	-3095	1370.34	-2.26	0.0285	0.3866
Type 2 vs 4	-3552.92	1046.61	-3.39	0.0014	0.0342
Type 2 vs 5	-1519.17	1250.94	-1.21	0.2305	0.9493
Type 2 vs 6	-11.6667	1078.18	-0.01	0.9914	1
Type 2 vs 7	158.33	1250.94	0.13	0.8998	1
Type 2 vs 8	352.18	956.47	0.37	0.7143	1
Type 2 vs 9	428.33	1118.88	0.38	0.7035	1
Type 3 vs 4	-457.92	1312	-0.35	0.7286	1
Type 3 vs 5	1575.83	1480.14	1.06	0.2924	0.9766
Type 3 vs 6	3083.33	1337.31	2.31	0.0255	0.3592
Type 3 vs 7	3253.33	1480.14	2.2	0.0328	0.4233
Type 3 vs 8	3447.18	1241.28	2.78	0.0078	0.1493
Type 3 vs 9	3523.33	1370.34	2.57	0.0133	0.2258
Type 4 vs 5	2033.75	1186.75	1.71	0.093	0.7353
Type 4 vs 6	3541.25	1002.99	3.53	0.0009	0.0238
Type 4 vs 7	3711.25	1186.75	3.13	0.003	0.0673
Type 4 vs 8	3905.1	870.84	4.48	<.0001	0.0014
Type 4 vs 9	3981.25	1046.61	3.8	0.0004	0.011
Type 5 vs 6	1507.5	1214.68	1.24	0.2206	0.9428
Type 5 vs 7	1677.5	1370.34	1.22	0.2269	0.947
Type 5 vs 8	1871.35	1108.07	1.69	0.0977	0.7501
Type 5 vs 9	1947.5	1250.94	1.56	0.1261	0.8225
Type 6 vs 7	170	1214.68	0.14	0.8893	1
Type 6 vs 8	363.85	908.53	0.4	0.6906	1
Type 6 vs 9	440	1078.18	0.41	0.685	1
Type 7 vs 8	193.85	1108.07	0.17	0.8619	1
Type 7 vs 9	270	1250.94	0.22	0.83	1
Type 8 vs 9	76.1538	956.47	0.08	0.9369	1

Table 18. ANOVA of pH (Tukey adjustment for heterogeneity)

Comparison	Difference Between Means	Standard Error	t Value	Pr > |t|	Adjusted p-value
Type 1 vs 2	0.2333	0.1985	1.18	0.2457	0.9578
Type 1 vs 3	0.7783	0.2431	3.2	0.0025	0.0564
Type 1 vs 4	0.9121	0.1857	4.91	<.0001	0.0004
Type 1 vs 5	0.9483	0.2431	3.9	0.0003	0.0085
Type 1 vs 6	0.594	0.1913	3.11	0.0032	0.0713
Type 1 vs 7	0.6633	0.2219	2.99	0.0044	0.0938
Type 1 vs 8	0.5014	0.1697	2.96	0.0049	0.1014
Type 1 vs 9	0.6283	0.1985	3.17	0.0027	0.0617
Type 2 vs 3	0.545	0.2431	2.24	0.0297	0.3969
Type 2 vs 4	0.6787	0.1857	3.66	0.0006	0.017
Type 2 vs 5	0.715	0.2431	2.94	0.0051	0.1047
Type 2 vs 6	0.3607	0.1913	1.89	0.0655	0.6263
Type 2 vs 7	0.43	0.2219	1.94	0.0587	0.5922
Type 2 vs 8	0.2681	0.1697	1.58	0.1208	0.8105
Type 2 vs 9	0.395	0.1985	1.99	0.0524	0.5576
Type 3 vs 4	0.1337	0.2327	0.57	0.5683	0.9997
Type 3 vs 5	0.17	0.2807	0.61	0.5477	0.9995
Type 3 vs 6	-0.1843	0.2372	-0.78	0.4412	0.997
Type 3 vs 7	-0.115	0.2626	-0.44	0.6634	1
Type 3 vs 8	-0.2769	0.2202	-1.26	0.2147	0.9384
Type 3 vs 9	-0.15	0.2431	-0.62	0.5402	0.9994
Type 4 vs 5	0.03625	0.2327	0.16	0.8769	1
Type 4 vs 6	-0.318	0.1779	-1.79	0.0803	0.6898
Type 4 vs 7	-0.2487	0.2105	-1.18	0.2433	0.9565
Type 4 vs 8	-0.4107	0.1545	-2.66	0.0107	0.1911
Type 4 vs 9	-0.2838	0.1857	-1.53	0.1331	0.8365
Type 5 vs 6	-0.3543	0.2372	-1.49	0.142	0.8529
Type 5 vs 7	-0.285	0.2626	-1.09	0.2833	0.9736
Type 5 vs 8	-0.4469	0.2202	-2.03	0.0481	0.5315
Type 5 vs 9	-0.32	0.2431	-1.32	0.1944	0.9213
Type 6 vs 7	0.06929	0.2155	0.32	0.7492	1
Type 6 vs 8	-0.09264	0.1612	-0.57	0.5682	0.9997
Type 6 vs 9	0.03429	0.1913	0.18	0.8585	1
Type 7 vs 8	-0.1619	0.1966	-0.82	0.4142	0.9955
Type 7 vs 9	-0.035	0.2219	-0.16	0.8754	1
Type 8 vs 9	0.1269	0.1697	0.75	0.4582	0.9977

Table 19. ANOVA of Temperature (Difference Between Means ˚C (95%CI))

	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9
Type 1	-0.25 (-3.0106 - 2.5106)	3.1667 (-0.2143 - 6.5477)	4.125 * (1.5427 - 6.7073)	3.3667 (-0.0143 - 6.7477)	1.0143 (-1.6459 - 3.6744)	-0.525 (-3.6114 - 2.5614)	1.9462 (-0.4137 - 4.306)	1.05 (-1.7106 - 3.8106)
Type 2		3.4167 * (0.0357 - 6.7977)	4.375 * (1.7927 - 6.9573)	3.6167 * (0.2357 - 6.9977)	1.2643 (-1.3959 - 3.9244)	-0.275 (-3.3614 - 2.8114)	2.1962 (-0.1637 - 4.556)	1.3 (-1.4606 - 4.0606)
Type 3			0.9583 (-2.2787 - 4.1954)	0.2 (-3.704 - 4.104)	-2.1524 (-5.4519 - 1.1471)	-3.6917 * (-7.3436 - -0.0398)	-1.2205 (-4.2831 - 1.8421)	-2.1167 (-5.4977 - 1.2643)
Type 4				-0.7583 (-3.9954 - 2.4787)	-3.1107 * (-5.5854 - -0.6361)	-4.65 * (-7.578 - -1.722)	-2.1788 * (-4.3274 - -0.0303)	-3.075 * (-5.6573 - -0.4927)
Type 5					-2.3524 (-5.6519 - 0.9471)	-3.8917 * (-7.5436 - -0.2398)	-1.4205 (-4.4831 - 1.6421)	-2.3167 (-5.6977 - 1.0643)
Type 6						-1.5393 (-4.5362 - 1.4576)	0.9319 (-1.3097 - 3.1734)	0.0357 (-2.6244 - 2.6959)
Type 7							2.4712 (-0.2627 - 5.2051)	1.575 (-1.5114 - 4.6614)
Type 8								-0.8962 (-3.256 - 1.4637)
Type 9								

* indicates statistical significance at alpha = 0.05

Table 20. ANOVA of Sludge Depth (Difference Between Means cm (95%CI))

	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9
Type 1	-	52.66 (-8.43 - 113.75)	4.66 (-56.44 - 65.75)	52.49 (-3.28 - 108.26)	48.24 (-7.53 - 104.01)	33.12 (-22.66 - 88.89)	84.3 * (41.65 - 126.94)	22.49 (-33.28 - 78.26)
Type 2		-	-	-	-	-	-	-
Type 3			-48.00 22.54	-0.17 (-66.16 - 65.82)	-4.42 (-70.41 - 61.57)	-19.55 (-85.53 - 46.44)	31.64 (-23.7 - 86.98)	-30.17 (-96.16 - 35.82)
Type 4				47.84 (-18.15 - 113.83)	43.58 (-22.41 - 109.57)	28.46 (-37.53 - 94.45)	79.64 * (24.3 - 134.98)	17.83 (-48.16 - 83.82)
Type 5					-4.25 (-65.35 - 56.84)	-19.38 (-80.47 - 41.72)	31.81 (-17.6 - 81.21)	-30 (-91.1 - 31.09)
Type 6						-15.13 (-76.22 - 45.97)	36.06 (-13.34 - 85.46)	-25.75 (-86.84 - 35.34)
Type 7							51.18 * (1.78 - 100.58)	-10.63 (-71.72 - 50.47)
Type 8								-61.81 * (-111.21 - - 12.41)
Type 9								

* indicates statistical significance at alpha = 0.05

Table 21. Correlation Matrix for Independent Variables in Regression Models

Spearman Correlation Coefficients, Prob > |r| under H0: Rho=0 (rows) / Pearson Correlation Coefficients, Prob > |r| under H0: Rho=0 (columns)	BOD	COD	TSS	pH	OG	*E. coli*	Type	Volume	# Filter	Temp.	Years in HH	Toilet Type	Emptying	# Users	Sludge Depth
BOD		**0.9913**	**0.3176**	-0.2463	**0.6906**	0.2172	-0.1833	-0.1941	0.0967	**0.2694**	0.0243	0.1960	-0.1186	**0.3332**	-0.1194
		<.0001	**0.0161**	0.0672	**<.0001**	0.1045	0.1724	0.1480	0.4743	**0.0447**	0.8601	0.1515	0.3794	**0.0113**	0.4573
COD	**0.9923**		**0.3065**	-0.2786	**0.7109**	0.2429	-0.1883	-0.1687	0.0589	**0.2675**	0.0301	0.1856	-0.1117	**0.3743**	-0.1490
	<.0001		**0.0204**	0.0376	**<.0001**	0.0686	0.1608	0.2098	0.6637	**0.0463**	0.8275	0.1750	0.4081	**0.0041**	0.3525
TSS	**0.4512**	**0.4701**		-0.3413	**0.3269**	0.2076	-0.0178	**-0.2740**	-0.1169	0.1142	-0.1326	0.0707	-0.0395	0.0035	-0.0234
	0.0004	**0.0002**		0.0100	**0.0131**	0.1212	0.8955	**0.0392**	0.3863	0.4018	0.3344	0.6081	0.7706	0.9792	0.8845
pH	-0.1909	-0.2155	**-0.3914**		-0.2311	-0.0903	-0.2528	0.1019	**0.4637**	**-0.3718**	-0.0973	-0.1181	0.0796	**-0.3273**	-0.0581
	0.1586	0.1107	**0.0029**		0.0867	0.5082	0.0601	0.4548	**0.0003**	**0.0048**	0.4840	0.3951	0.5598	**0.0138**	0.7216
OG	0.6491	0.6429	0.5706	-0.1018		**0.3514**	-0.2421	**-0.3433**	-0.1204	**0.3013**	-0.2330	-0.1607	**-0.3368**	0.1794	-0.2873
	<.0001	**<.0001**	**<.0001**	0.4554		**0.0074**	0.0697	**0.0089**	0.3724	**0.0241**	0.0869	0.2413	**0.0104**	0.1817	0.0686
E. coli	0.1266	0.1617	**0.3179**	-0.0504	**0.3532**		**-0.3196**	**-0.3710**	-0.0591	0.2507	**-0.3294**	-0.0532	-0.1027	-0.0357	**-0.3382**
	0.3482	0.2295	**0.0160**	0.7121	**0.0070**		**0.0154**	**0.0045**	0.6624	0.0624	**0.0141**	0.6998	0.4473	0.7920	**0.0306**
Type	-0.2372	-0.2547	-0.1581	-0.1945	**-0.3258**	**-0.3424**		**0.3991**	-0.5515	0.0731	**0.3423**	0.2033	0.1698	-0.0275	**0.5189**
	0.0756	0.0559	0.2400	0.1509	**0.0134**	**0.0091**		**0.0021**	<.0001	0.5925	**0.0105**	0.1366	0.2067	0.8391	**0.0005**
Volume	-0.1128	-0.1044	**-0.3545**	**0.2786**	**-0.3723**	**-0.3806**	**0.3270**		-0.0367	**-0.4314**	**0.4278**	0.0534	0.2494	0.1217	-0.2265
	0.4034	0.4398	**0.0068**	**0.0376**	**0.0043**	**0.0035**	**0.0130**		0.7865	**0.0009**	**0.0011**	0.6986	0.0614	0.3670	0.1545
# Filter	0.2402	0.2148	-0.1553	**0.4023**	0.1290	-0.0876	**-0.4621**	0.1894		**-0.3237**	0.0082	0.0891	0.1339	-0.0365	-0.2195
	0.0719	0.1085	0.2488	**0.0021**	0.3388	0.5170	**0.0003**	0.1583		**0.0149**	0.9528	0.5177	0.3208	0.7874	0.1680
Temp.	0.2388	0.2324	**0.2691**	**-0.3553**	0.2118	0.2485	0.0945	**-0.5446**	**-0.3399**		-0.1900	0.1623	-0.0521	-0.1090	0.2326
	0.0763	0.0848	**0.0450**	**0.0072**	0.1171	0.0648	0.4886	**<.0001**	**0.0104**		0.1689	0.2411	0.7027	0.4239	0.1487
Years in HH	0.0816	0.0917	-0.1388	-0.0971	**-0.2774**	**-0.3631**	**0.3897**	**0.2934**	0.2003	-0.0069		**0.5179**	0.2223	0.2618	0.2084
	0.5537	0.5053	0.3121	0.4849	**0.0404**	**0.0064**	**0.0033**	**0.0297**	0.1426	0.9605		**<.0001**	0.1029	0.0535	0.1970
Toilet Type	**0.2926**	**0.2817**	-0.0773	-0.0585	0.0269	-0.0473	0.1966	0.0850	**0.2739**	0.1501	**0.6236**		0.0128	0.2465	**0.3344**
	0.0302	**0.0372**	0.5747	0.6745	0.8454	0.7319	0.1502	0.5375	**0.0430**	0.2788	**<.0001**		0.9264	0.0697	**0.0350**
Emptying	-0.0601	-0.0457	-0.0226	0.0413	-0.2153	-0.0863	0.1631	**0.2786**	0.1303	-0.0745	0.2163	0.0625		-0.1950	-0.0644
	0.6571	0.7360	0.8672	0.7626	0.1077	0.5234	0.2254	**0.0359**	0.3340	0.5851	0.1126	0.6501		0.1460	0.6891
# Users	**0.2920**	**0.3042**	0.0902	**-0.3446**	0.1109	-0.0467	-0.1017	0.0087	0.0858	-0.0086	0.1790	0.2414	-0.2038		0.0862
	0.0275	**0.0214**	0.5044	**0.0093**	0.4114	0.7302	0.4517	0.9486	0.5256	0.9499	0.1909	0.0758	0.1284		0.5922
Sludge Depth	-0.1458	-0.1565	-0.0630	-0.0673	-0.1492	-0.2734	**0.5658**	-0.2357	-0.2337	0.2237	**0.3863**	**0.3212**	-0.1825	0.0565	
	0.3631	0.3285	0.6958	0.6799	0.3517	0.0837	**0.0001**	0.1379	0.1414	0.1652	**0.0138**	**0.0433**	0.2534	0.7258	

Table 22. Simple Linear Regression – Potential Predictor Variables

Simple Linear Regression									
Independent Predictor Value Dependent Variable	**F-value**	**p-value**	**R-square**	**Adjusted R-square**	**Independent Predictor Value** Dependent Variable	**F-value**	**p-value**	**R-square**	**Adjusted R-square**
Type					**Type of Toilet**				
BOD	3.00	**0.0083**	**0.3330**	0.2219	BOD	2.12	0.1515	0.0384	0.0203
COD	2.84	**0.0115**	**0.3213**	0.2082	COD	1.89	0.1750	0.0344	0.0162
pH	4.47	**0.0004**	**0.4323**	0.3357	pH	0.74	0.3951	0.0139	-0.0050
TSS	2.32	**0.0340**	**0.2791**	0.1589	TSS	0.27	0.6081	0.0050	-0.0138
OG	3.15	**0.0060**	**0.3442**	0.2349	OG	1.40	0.2413	0.0258	0.0074
E. coli	3.88	**0.0014**	**0.3924**	0.2912	*E. coli*	0.15	0.6998	0.0028	-0.0160
Volume					**System Emptying**				
BOD	2.15	0.1480	0.0377	0.0202	BOD	0.79	0.3794	0.0141	-0.0039
COD	1.61	0.2098	0.0284	0.0108	COD	0.69	0.4081	0.0125	-0.0055
pH	0.57	0.4548	0.0104	-0.0079	pH	0.34	0.5598	0.0063	-0.0121
TSS	4.46	**0.0392**	**0.0751**	0.0582	TSS	0.09	0.7706	0.0016	-0.0166
OG	7.35	**0.0089**	**0.1179**	0.1018	OG	7.04	**0.0104**	**0.1135**	0.0973
E. coli	8.78	**0.0045**	**0.1376**	0.1220	*E. coli*	0.59	0.4473	0.0105	-0.0075
Number of Filters					**Number of Household Members**				
BOD	0.52	0.4743	0.0093	-0.0087	BOD	6.87	**0.0113**	**0.1110**	0.0948
COD	0.19	0.6637	0.0035	-0.0147	COD	8.96	**0.0041**	**0.1401**	0.1244
pH	14.79	**0.0003**	**0.2150**	0.2004	pH	6.48	**0.0138**	**0.1071**	0.0906
TSS	0.76	0.3863	0.0137	-0.0043	TSS	0.00	0.9792	0.0000	-0.0182
OG	0.81	0.3724	0.0145	-0.0034	OG	1.83	0.1817	0.0322	0.0146
E. coli	0.19	0.6624	0.0035	-0.0146	*E. coli*	0.07	0.7920	0.0013	-0.0169
Temperature					**Sludge Accumulation**				
BOD	4.22	**0.0447**	**0.0726**	0.0554	BOD	0.56	0.4573	0.0142	-0.0110
COD	4.16	**0.0463**	**0.0716**	0.0544	COD	0.89	0.3525	0.0222	-0.0029
pH	8.66	**0.0048**	**0.1383**	0.1223	pH	0.13	0.7216	0.0034	-0.0228
TSS	0.71	0.4018	0.0130	-0.0052	TSS	0.02	0.8845	0.0005	-0.0251
OG	5.39	**0.0241**	**0.0908**	0.0739	OG	3.51	0.0686	0.0825	0.0590
E. coli	3.62	0.0624	0.0629	0.0455	*E. coli*	5.04	**0.0306**	**0.1144**	0.0917
Years Lived in Household									
BOD	0.03	0.8601	0.0006	-0.0183					
COD	0.05	0.8275	0.0009	-0.0179					
pH	0.50	0.4840	0.0095	-0.0096					
TSS	0.95	0.3344	0.0176	-0.0009					
OG	3.04	0.0869	0.0543	0.0365					
E. coli	6.45	**0.0141**	**0.1085**	0.0917					

Table 23. Simple Linear Regression – Treatment Factors

Simple Linear Regression				
Independent Predictor Value Dependent Variable	**F-value**	**p-value**	**R-square**	**Adjusted R-square**
BOD				
COD	3120.83	**<.0001**	**0.9827**	0.9824
pH	3.49	0.0672	0.0607	0.0433
TSS	6.17	**0.0161**	**0.1009**	0.0845
OG	50.14	**<.0001**	**0.4769**	0.4674
E. coli	2.72	0.1045	0.0472	0.0299
COD				
BOD	3120.83	**<.0001**	**0.9827**	0.9824
pH	4.54	**0.0376**	**0.0776**	0.0605
TSS	5.70	**0.0204**	**0.0939**	0.0774
OG	56.18	**<.0001**	**0.5053**	0.4963
E. coli	3.45	0.0686	0.0590	0.0419
pH				
BOD	3.49	0.0672	0.0607	0.0433
COD	4.54	**0.0376**	**0.0776**	0.0605
TSS	7.12	**0.0100**	**0.1165**	0.1001
OG	3.05	0.0867	0.0534	0.0359
E. coli	0.44	0.5082	0.0081	-0.0102
TSS				
BOD	6.17	**0.0161**	**0.1009**	0.0845
COD	5.70	**0.0204**	**0.0939**	0.0774
pH	7.12	**0.0100**	**0.1165**	0.1001
OG	6.58	**0.0131**	**0.1068**	0.0906
E. coli	2.48	0.1212	0.0431	0.0257
OG				
BOD	50.14	**<.0001**	**0.4769**	0.4674
COD	56.18	**<.0001**	**0.5053**	0.4963
pH	3.05	0.0867	0.0534	0.0359
TSS	6.58	**0.0131**	**0.1068**	0.0906
E. coli	7.75	**0.0074**	**0.1235**	0.1075
E. coli				
BOD	2.72	0.1045	0.0472	0.0299
COD	3.45	0.0686	0.0590	0.0419
pH	0.44	0.5082	0.0081	-0.0102
TSS	2.48	0.1212	0.0431	0.0257
OG	7.75	**0.0074**	**0.1235**	0.1075

Table 24. Ridge Regression Results (R version 3.2.3)

Independent Variable	Estimate	Standard Error (StdEst)	t-value (StdEst)	Pr(>|t|)		Independent Variable	Estimate	Standard Error (StdEst)	t-value (StdEst)	Pr(>|t|)	
BOD (λ = 0.002)						**TSS (λ = 3.509)**					
Intercept	-3.82E+01	6.87E+02	-545.965	<0.0001	***	Intercept	3.56E+02	7.13E+02	-756.232	<0.0001	***
COD	3.25E-01	3.07E+01	33.268	<0.0001	***	BOD	5.53E-02	3.22E+01	1.696	0.0899	.
TSS	2.62E-02	1.98E+01	1.893	0.0583	.	COD	1.53E-02	3.16E+01	1.519	0.1287	
pH	8.56E+00	2.44E+01	1.005	0.3149		pH	-3.27E+01	3.90E+01	-2.398	0.0165	*
OG	-8.85E-02	3.22E+01	-1.082	0.2794		OG	1.99E-01	3.43E+01	2.281	0.0225	*
E. coli	-2.27E-03	2.06E+01	-1.727	0.0842	.	E. coli	3.94E-03	4.02E+01	1.541	0.1233	
Temperature	5.96E-01	2.38E+01	0.36	0.719		Temperature	3.36E-01	3.94E+01	0.123	0.9023	
Volume	-3.43E+00	2.52E+01	-0.679	0.4971		Volume	-9.53E+00	3.83E+01	-1.238	0.2159	
# Filter	4.47E+00	2.39E+01	1.152	0.2495		# Filter	-7.30E+00	3.99E+01	-1.125	0.2606	
Years in HH	4.73E-02	2.48E+01	0.259	0.7954		Years in HH	-3.81E-01	3.83E+01	-1.351	0.1767	
Type of Toilet	2.53E-01	2.42E+01	0.045	0.9641		Type of Toilet	-1.44E+00	3.97E+01	-0.156	0.8762	
Emptying	-7.94E+00	2.06E+01	-1.41	0.1584		Emptying	-9.14E-01	4.16E+01	-0.08	0.936	
# HH Members	-2.77E+00	2.31E+01	-1.747	0.0806	.	# HH Members	4.90E-01	3.92E+01	0.182	0.8559	
Age of Tank	1.64E+00	2.06E+01	1.418	0.1562		Age of Tank	-8.24E-01	4.16E+01	-0.352	0.7251	
COD (λ = 0.003)						**OG (λ = 0.355)**					
Intercept	5.37E+01	8.32E+02	-1789.147	<0.0001	***	Intercept	9.67E+00	6.82E+02	-485.008	<0.0001	***
BOD	2.93E+00	8.69E+01	33.342	<0.0001	***	BOD	1.03E-01	1.63E+01	6.223	<0.0001	***
TSS	-7.56E-02	5.97E+01	-1.816	0.0693	.	COD	3.67E-02	1.59E+01	7.279	<0.0001	***
pH	-2.63E+01	7.30E+01	-1.029	0.3037		TSS	2.51E-02	2.57E+01	1.403	0.1607	
OG	5.48E-01	9.32E+01	2.32	0.0204	*	pH	-2.08E+00	2.56E+01	-0.232	0.8166	
E. coli	7.06E-03	6.18E+01	1.796	0.0725	.	E. coli	1.82E-03	2.58E+01	1.109	0.2673	
Temperature	-2.96E-01	7.15E+01	-0.059	0.9526		Temperature	1.79E+00	2.53E+01	1.017	0.3092	
Volume	1.41E+01	7.52E+01	0.935	0.3499		Volume	-8.72E+00	2.56E+01	-1.699	0.0893	.
# Filter	-8.94E+00	7.21E+01	-0.763	0.4455		# Filter	-3.38E+00	2.51E+01	-0.828	0.4075	
Years in HH	-1.84E-01	7.43E+01	-0.337	0.7364		Years in HH	4.40E-03	2.58E+01	0.023	0.9815	
Type of Toilet	5.16E+00	7.24E+01	0.306	0.7594		Type of Toilet	-1.45E+01	2.55E+01	-2.454	0.0141	*
Emptying	2.91E+01	6.12E+01	1.74	0.0818	.	Emptying	-1.64E+01	2.52E+01	-2.38	0.0173	*
# HH Members	1.11E+01	6.77E+01	2.384	0.0171	*	# HH Members	-5.72E-01	2.58E+01	-0.323	0.7468	
Age of Tank	-4.43E+00	6.19E+01	-1.268	0. 2047		Age of Tank	-1.58E+00	2.52E+01	-1.115	0.2648	

Independent Variable	Estimate	Standard Error (StdEst)	t-value (StdEst)	Pr(>|t|)	
pH (λ = 0.498)					
Intercept	8.21E+00	6.75E+02	0.116	<0.0001	***
BOD	-1.79E-05	1.39E-01	-0.127	0.8987	
COD	-4.40E-05	1.29E-01	-1.069	0.2850	
TSS	-3.20E-04	2.16E-01	-2.121	0.0339	*
OG	-1.76E-04	1.97E-01	-0.353	0.7244	
E. coli	8.65E-07	2.16E-01	0.063	0.9497	
Temperature	-2.59E-02	2.09E-01	-1.785	0.0743	.
Volume	1.32E-02	2.08E-01	0.316	0.7519	
# Filter	1.44E-01	2.10E-01	4.237	<0.0001	***
Years in HH	-2.90E-04	2.09E-01	-0.189	0.8502	
Type of Toilet	-2.05E-02	2.07E-01	-0.424	0.6713	
Emptying	-2.06E-02	2.12E-01	-0.355	0.7224	
# HH Members	-4.43E-02	2.14E-01	-3.014	0.0026	**
Age of Tank	7.40E-03	2.11E-01	0.621	0.5344	
Sludge Depth (λ = 0.503)					
Intercept	-7.47E+01	5.74E+02	217.352	<0.0001	***
BOD	1.04E-03	1.29E+01	0.074	0.9414	
COD	-2.09E-03	1.18E+01	-0.517	0.6055	
TSS	2.42E-03	1.97E+01	0.166	0.8679	
pH	4.27E+00	1.89E+01	0.565	0.5723	
OG	-1.04E-01	1.63E+01	-2.437	0.0148	*
E. coli	-1.17E-03	1.95E+01	-0.8	0.4239	
Temperature	2.74E+00	1.87E+01	1.691	0.0908	.
Volume	-9.16E+00	1.84E+01	-1.985	0.0471	*
# Filter	-3.31E+00	1.82E+01	-1	0.3174	
Years in HH	1.28E-01	1.90E+01	0.821	0.4119	
Type of Toilet	1.26E+01	1.86E+01	2.567	0.0103	*
Emptying	-2.39E+00	1.92E+01	-0.358	0.7207	
# HH Members	1.68E+00	1.91E+01	1.122	0.262	
Age of Tank	5.09E+00	1.91E+01	4.289	<0.0001	***

Independent Variable	Estimate	Standard Error (StdEst)	t-value (StdEst)	Pr(>|t|)	
E. coli (λ = 1.898)					
Intercept	8.47E+03	3.17E+03	-176.604	<0.0001	***
BOD	2.79E-01	4.80E+02	0.573	0.5664	
COD	1.69E-01	4.67E+02	1.138	0.2550	
TSS	6.45E-01	6.75E+02	1.369	0.1709	
pH	-5.86E+01	6.23E+02	-0.269	0.7879	
OG	2.95E+00	5.47E+02	2.122	0.0338	*
Temperature	3.64E+01	6.41E+02	0.816	0.4146	
Volume	-2.82E+02	6.27E+02	-2.234	0.0255	*
# Filter	-7.94E+01	6.45E+02	-0.759	0.4481	
Years in HH	-8.60E+00	6.20E+02	-1.881	0.0600	.
Type of Toilet	-2.46E+02	6.46E+02	-1.635	0.1021	
Emptying	-5.84E+01	6.81E+02	-0.313	0.7541	
# HH Members	-2.86E+01	6.39E+02	-0.65	0.5154	
Age of Tank	-7.84E+01	6.88E+02	-2.025	0.0429	*

Significance Levels: ***=0.001, **=0.01, *=0.05, .=0.1