Understanding Socio-technical Barriers to Operationalizing Responsible Management Entities of Decentralized Wastewater Systems in the Black Belt Region of Rural Alabama

INTRODUCTION

Over the past few decades, the Black Belt region of Alabama has been struggling from inadequate wastewater management (Elliott et al. 2017; White et al. 2020; White and Jones 2006; Winkler and Flowers 2017). In addition to the region being characterized by low-population density, rural poverty, and lack of economic development, the geological soil conditions have further exacerbated the wastewater crisis in these underserved communities (Elliott et al. 2017; Maxcy-Brown et al. 2021; Meza 2018; White et al. 2020). Because of the dense clay soil in the Black Belt region, traditional onsite wastewater systems—septic tanks and drain fields—cannot adequately infiltrate wastewater into the ground. These challenging conditions have resulted in the presence of raw wastewater on the ground surface at many rural homes, as well as consequential public health issues (White et al. 2020). Field surveys of hundreds of rural residences in three counties (Bibb, Wilcox, and Hale)—performed in 2005 and 2017—have documented that over 50% of rural residents have raw sewage on the ground surface; residents have resorted to the use of "straight pipes" for a direct raw sewage discharge due to the hydraulic failure of their septic systems (White and Jones 2006). Additional studies in Lowndes County and Wilcox County have shown high prevalence of intestinal parasites (worms) among both adults and children associated with the poor sanitation (Badham 1993; McKenna et al. 2017). Such unacceptable sanitation conditions have drawn both national and international attention (Maxcy-Brown et al. 2021; US-EPA 2021; Winkler and Flowers 2017) and spurred research efforts to explore alternative decentralized wastewater management and regulatory actions that can address wastewater issues in the Black Belt communities (White et al. 2020).

Research Problem. Given widespread poverty as well as low-population density leading to a limited number of rate payers (White and Jones 2006), advanced onsite wastewater treatment systems for these soil conditions are not financially feasible in the Black Belt and even unaffordable for the majority of the residents (Maxcy-Brown et al. 2021). Ongoing research efforts (CARWW 2022; White 2022; White et al. 2020) are instead investigating effluent sewer and treatment clusters (e.g., 100-to-150 homes) suitable for connection to a potential decentralized wastewater system. Such a decentralized model involves collecting wastewater from multiple dwellings and conveying it to a shared treatment and dispersal system located somewhat near the dwellings (US-EPA 2005)—referred hereafter to as a *clustered* system. While such decentralized wastewater solutions seem promising for addressing the ongoing wastewater challenges in the Black Belt communities (CARWW 2022; White 2022), how to best manage these small clustered systems is not well understood. If improperly managed, though, decentralized systems do not provide the level of treatment necessary to adequately protect public health and water quality (US-EPA 2003).

Providing proper operations and maintenance (O&M) services to these systems—through a responsible management entity (RME)—is needed to ensure their adequate performance, reliability, and long-term sustainability (US-EPA 2005, 2018, 2003). An RME is defined as a legal organization with the technical, managerial, and financial capacity to operate and maintain viable decentralized wastewater systems within the RME's jurisdiction (US-EPA 2005). For instance, various types of RMEs could be considered for handling the O&M of decentralized wastewater systems, including public and private service providers (e.g., water and wastewater utilities), as well as non-profit corporations (Murphy et al. 2005; Pinkham et al. 2004; US-EPA 2005). A single RME can handle multiple individual onsite systems and clustered systems, and RMEs often seek to maximize the number of dwellings served to maintain its financial sustainability (Murphy et al. 2005; US-EPA 2005). Given that the Black Belt is mostly a rural region with small spread-out residential clusters (White and Jones 2006), it may be more financially viable to assign an existing RME to manage the alternative clustered systems in this region.

According to US-EPA (2003), decentralized responsible management requirements vary based on the treatment system's complexity, as well as environmental sensitivity or public health concerns of an area. In this regard, a five-level conceptual management framework exists, ranging from programs with least management controls—primarily adequate for conventional onsite septic systems that require little owner attention—to programs with higher management restrictions (US-EPA, 2003). More specifically, these management alternatives include: (1) homeowner awareness model, (2) maintenance contract model, (3) operating permit model, (4) RME operation and maintenance model, and (5) RME ownership model. Among these alternatives, the RME ownership model makes the management of decentralized wastewater systems similar to the utility management of centralized systems.

Important to note that the responsible management of decentralized wastewater systems in small, rural communities is complex. This complexity stems from the widespread poverty in these communities, as well as the limited number of rate payers, which in turn impact the financial sustainability of RMEs. In addition to these constraints, the RMEs' consideration to manage alternative decentralized wastewater systems—such as those proposed for the Black Belt region—may be influenced by various barriers that span the technical, financial, regulatory/institutional, and social dimensions (Bakchan and White 2022; Etnier et al. 2007; Olenik 1995; Pinkham et al. 2004; US-EPA 1997)—referred hereafter to as *socio-technical barriers*. As such, to effectively operationalize adequate RMEs to ensure sustainable O&M, we need to better understand possible socio-technical barriers that may hinder RMEs' operations in the Black Belt communities. Uncovering such socio-technical barriers would potentially highlight policy areas that require further consideration to overcome influential barriers, thereby enabling more effective responsible management solutions.

Research Objectives. The objective of this study is two-fold. First, the study identifies major socio-technical barriers to managing decentralized systems by exploring literature related to decentralized wastewater management models. Second, the study empirically assesses the impacts

of the identified socio-technical barriers on RMEs' considerations to provide O&M services to alternative clustered wastewater systems in the Black Belt.

MATERIAL AND METHODS

Survey Questionnaire and Data Collection. The study is enabled by a survey questionnaire administered to small-, medium-, and large-sized public and private entities (e.g., water utilities, sewer utilities, non-profit organizations, community development corporations), operating across different states in the US. The questions cover topics related to the participants' demographics and experience in their respective organizations, the entity type and structure (e.g., public service provider, private agencies, non-profit), the type of service provided (e.g., water, sewer, hybrid), whether the entity currently operates small decentralized wastewater systems, the entity's potential consideration to operate and maintain new alternative clustered systems, and a set of major barriers to effective decentralized wastewater management spanning the technical, financial, regulatory/institutional, and social dimensions (identified from literature; see Table 1 in the Findings section). Participants were asked to specify if these listed barriers are possible reasons that may prevent them from considering operating and managing such alternative clustered wastewater systems, and accordingly rate the importance of these reasons based on a 5-point Likert scale (very important, important, neutral, somewhat important, not important). This question is included here:

- *What are possible barriers that may prevent you from operating and managing such alternative decentralized wastewater systems? Please rate the importance of these barriers to you.*

Data collection was conducted between March 2022 and January 2023. The final sample consisted of 121 responses from 121 entities, spanning 27 states. Important to note that we targeted a single response per entity, as our objective is to capture entities' insights into socio-technical barriers to serving as potential RMEs. We examined the data completeness of the data set; this yielded 114 complete responses that were used for model development.

Analysis Methods. Binomial logistic (BL) regression was used (King 2008), given that the dependent variable (i.e., RMEs' consideration to provide O&M services) is a dichotomous variable ("1" indicates consideration and "0" non-consideration). A BL regression model predicts the probability that an outcome falls into one of the two categories of a dichotomous dependent variable based on predictors. Notably, the *odds ratios*, along with their confidence interval (CI), are commonly used to interpret the effects of predictors on the dependent variable. An odds ratio greater than 1 means that the outcome is more likely to occur (compared to non-occurrence), whereas an adds ratio less than 1 indicates that the outcome is less likely to occur (King 2008). In addition to the independent variables denoting the socio-technical barriers, we considered other control variables for model development, such as the entity type (e.g., public, private) and the entity's primary location of operation.

KEY FINDINGS

To identify the various socio-technical barriers, we turned to literature related to decentralized wastewater management models (see Table 1). BL regression results (Table 2) show that only "operator turnover" and "inflexible regulatory codes" are the influential barriers to the consideration of providing O&M services to alternative clustered systems, with 1% and 5% significance level, respectively.

Table 1. Primary barriers to effective decentralized wastewater management, identified from literature

Barrier	Description
Technical	
Limited technical assistance	• Limited technical assistance in regard to O&M of non-conventional decentralized wastewater systems (Etnier et al. 2007; Mitchell et al. 2008; Pinkham et al. 2004; US-EPA 1997)
Operator turnover	• Difficulty to retain skilled and certified operators due to high turnover in rural areas (Mitchell et al. 2008)
Financial	
Limited financial incentives	• Limited to no financial incentives to manage new alternative decentralized wastewater systems in rural areas (Mitchell et al. 2008; US-EPA 1997)
Difficulty to obtain funds	• Difficulty to obtain public funds/capital for privately owned or managed systems (Mitchell et al. 2008; US-EPA 1997)
Limited financial capacity	• Limited communities' financial capacity to pay for the O&M of decentralized wastewater systems (Mitchell et al. 2008; Murphy et al. 2005; Pinkham et al. 2004)
Unclear operational cost	• Unclear operational cost of alternative decentralized solutions (Pinkham et al. 2004)
Regulatory/Institutional	
Inflexible regulatory codes	• Inflexible and prescriptive regulatory codes that may hinder the inclusion of new alternative systems or the operation of systems outside the entity's service area and jurisdiction (Pinkham et al. 2004; US-EPA 1997)
Lack of organizational structures	• Lack of necessary organizational and managerial structures for effectively managing alternative decentralized wastewater systems (Pinkham et al. 2004; US-EPA 1997)
Liability concerns	• Potential liability associated with managing unfamiliar systems and possible consequential system failures (Pinkham et al. 2004)
Social	
Lack of awareness to consequences of failing systems	• Lack of communities' awareness to possible environmental and public health risks associated with failing wastewater systems, which may impact their willingness to pay for the O&M of alternative systems (Pinkham et al. 2004; US-EPA 1997)
Equity concerns	• Potential change in community socio-demographics (due to potential increase in property taxes often associated with improved access to basic services) and concerns of not meeting community's actual needs (Pinkham et al. 2004)

Table 2. Odd ratios results for the two statistically significant socio-technical barriers [a]

Variable	Odd Ratios	2.5%	97.5%	*p*
Operator turnover	0.13	0.03	0.49	0.004^{***}
Inflexible regulatory codes	4.63	1.24	20.02	0.03^{**}

[a] BL regression analysis – odd ratios at 95% CI. $^{*}p < 0.1$. $^{**}p < 0.05$. $^{***}p < 0.01$.

Model information: Null deviance = 150.049 on 113 degrees of freedom; Residual deviance= 96.373 on 95 degrees of freedom; AIC = 134.37; Number of Fisher scoring iterations = 5; McFadden's *pseudo-*R^2 = 0.36.

There is high wastewater operator turnover and difficulty to retain skilled operators in the Black Belt communities. Once operators get certified, they often seek better opportunities outside the region. The decline in intellectual properties in the water sector is an ongoing national challenge, especially exacerbated in rural communities. Similar to the rural Alabama Black Belt, operator turnover in rural Alaska, and the loss of institutional knowledge associated with that, make managing water-sector systems difficult (Spearing et al. 2022). Respondents seem to be highly concerned about this workforce barrier in the Black Belt, as it would probably increase their hurdle to conduct timely O&M services and respond to issues as they arise. As such, novel mechanisms are needed to build brain talent and address workforce shortage, such as developing educational programs to train wastewater operators to get certified, supported by continuous technical assistance and development as well as federal and/or state funding to support these efforts. For instance, vocational-technical programs in high schools and/or community college workforce training programs might be options to develop talent in the water-wastewater sector.

Additionally, regulatory barriers—such as those related to wastewater discharge permitting—are among the most concerning barriers to participants, impacting their consideration to provide O&M services to alternative clustered systems. Surface discharge of treated effluent from conventional onsite wastewater treatment systems is still not permitted under current Alabama regulations. With such a regulatory constraint, respondents may be concerned about RMEs' ability to obtain operating permits for alternative treatment solutions. As such, to provide technically feasible and sustainable decentralized solutions, alternative regulatory oversight and guidance is needed, such as introducing a new permit class that aligns with the Black Belt region's environmental constraints (clay soils).

IMPLICATIONS

The study advances existing knowledge through providing an empirical understanding to socio-technical barriers' impacts on RMEs' consideration to provide O&M services to alternative wastewater treatment solutions in small, rural communities—an existing limitation in literature. These efforts, in turn, contributes to addressing the theoretical complexity of the responsible management of decentralized clustered wastewater systems. Building off of this understanding, this study sets the stage to provide practical and policy recommendations that could best overcome

the identified barriers. Accordingly, RMEs would be better enabled to provide adequate O&M services and consequently contribute to addressing the wastewater challenges in small, rural, underserved communities in the US.

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