The Policy Foundations of Decentralized Wastewater Infrastructure Failure in Rural Alabama's Black Belt

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ABSTRACT

Policy work is often framed as the remedy to infrastructure gaps and challenges. In limited-resource rural communities, however, policies designed around generalized assumptions can create added burdens when they exceed local capacity, labor availability, and implementation reach. In decentralized wastewater systems, this possibility remains underexamined despite growing attention to treatment technologies, management models, and workforce barriers. This study examines how adopted policies shape decentralized wastewater challenges in Alabama's Black Belt. Using 20 semi-structured interviews with community stakeholders, we identified recurring structural challenges through inductive thematic analysis, then traced those challenges to relevant state and federal policy contributors through iterative review of adopted codes, rules, program requirements, and agency guidance. Four challenge areas emerged: limited institutional capacity, operations and compliance constraints, licensing and certification misalignment, and project delivery disincentives. The findings show that these challenges are reinforced by standardized policy requirements, such as funding match expectations, operator staffing and certification rules, and compliance obligations tied to federally assisted projects. These findings show how policy can become part of the problem when one-size-fits-all requirements are applied to limited-resource rural communities even if the policy was designed with fiscal and technical responsibility at heart. The study identifies concrete reform needs, including right-sized compliance expectations, decentralized certification pathways, and funding structures that do not penalize communities for lacking the very capacity these policies intend to fulfill. Our work shifts the narrative away from attributing failure to limited-resource rural communities and toward recognizing how state and federal policy structures can shape these burdens, while offering actionable recommendations for policy reform.

INTRODUCTION

Home to half a million residents, the 17-county Black Belt region of rural Alabama lacks access to basic wastewater services (Maxcy-Brown et al., 2024). The region's dense swell-shrink clayey soils cause hydraulic failure in conventional onsite wastewater treatment systems (e.g., septic tanks and drainfields), making them ineffective. As a result, many households rely on straight pipes for discharging untreated sewage directly onto the ground, leading to significant environmental contamination and public health risks (Maxcy-Brown et al., 2024). For example, a survey of 2,000 unsewered homes found that 50% exhibited visible signs of untreated wastewater on the surface (White & Jones, 2006), while exposure to raw sewage has led to 5% of 227 blood samples testing positive for roundworm infection (Poole et al., 2023). These issues are exacerbated by the region's socioeconomic conditions, with up to 40% of residents living below the US poverty line (Maxcy-Brown et al., 2024).

Ongoing research efforts are investigating innovative decentralized wastewater treatment solutions, management models, and regulatory reforms to address wastewater infrastructure issues in the Black Belt (Allaire et al., 2024; Bakchan et al., 2022; Bakchan & White, 2024; Elliott et al., 2023). For instance, Bakchan and White (2024b) examine the formation of responsible management entities for decentralized wastewater systems' operation and maintenance (O&M), whereas Kordahi and Bakchan (2025) identify challenges that emerged at the intersection of different workforce career pathways. These initiatives represent significant progress toward sustainable wastewater infrastructure solutions for the Black Belt communities. However, despite this progress, limited attention has been given to explicitly examining parallels between adopted policies and structural challenges. Unfortunately, policy changes in Alabama are often stuck in long and overly complex bureaucratic processes and are consequently disconnected from the realities of the communities they are meant to serve (Kordahi & Bakchan, 2025).

Research Problem. The Black Belt faces persistent policy and governance challenges that constrain the implementation of decentralized wastewater management solutions, exacerbating fragmented regulatory oversight, limited institutional capacity, and misalignment between state-level policies and local needs (Kordahi & Bakchan, 2025). As such, to enable effective decentralized wastewater management in the Black Belt, it is necessary to expose the policy-driven challenges and institutional dynamics that shape—and often reinforce—the persistent barriers faced by decentralized wastewater systems within these communities.

Research objectives. This study seeks to identify the structural challenges shaping decentralized wastewater management in the Black Belt and the policies that may sustain these challenges. Understanding how these challenges align with, diverge from, or are reproduced by existing policy frameworks and regulatory practices is essential for revealing the closed feedback between on-the-ground conditions and policy responses. In doing so, the study contributes to policy and governance scholarship on socio-technical infrastructure systems by demonstrating how institutional rules can actively reproduce infrastructure barriers in limited-resource rural contexts.

MATERIAL AND METHODS

Data Collection. To investigate challenges for decentralized wastewater management, we conducted 20 semi-structured interviews with community stakeholders. The data collection adhered to the APA guidelines for qualitative data collection by addressing 28 of the 32 items in the Consolidated Criteria for Reporting Qualitative Research (COREQ) (Tong et al., 2007), while the remaining four were deemed irrelevant for this study. We began with questions addressing general challenges, then transitioned to a flexible, respondent-driven discussion focused on each participant's specific experience with mandated policies and regulations. This approach minimized interviewer influence, allowing responses to better reflect each participant's unique perspective and expertise. Stakeholders were selected using convenience and snowball sampling methods (Noy, 2008) with participants chosen for their expertise in decentralized wastewater management, policy-mandated requirements, and socio-technical dynamics in the Black Belt. The interviewees represented diverse stakeholder groups, including community grant writers (two), engineers (five), operators (two), community activists and residents (three), representatives from local government agencies (three), private utility owners (three), and university professors (two). Interviews were conducted between September 14, 2022, and February 8, 2023, via teleconferencing or phone. All interviews were recorded with permission, transcribed, and anonymized to ensure confidentiality. The wastewater crisis in Alabama's Black Belt is not new; it has remained largely stagnant for decades. White and Jones (2006) documented failing onsite sanitation systems nearly two decades ago, and Barnett et al. (2025) show that these conditions continue to shape sanitation insecurity today. The persistence of the crisis suggests that Black Belt communities have fallen—and continue to fall—between the cracks of contemporary infrastructure policy reforms. This long-standing policy gap further highlights the need for the present study.

Analysis Method. This study begins with an inductive thematic analysis (Bakchan et al., 2026; Braun & Clarke, 2006) to explore challenges shaping decentralized wastewater management in the Black Belt. We then proceed to iteratively condense and group these challenges into higher-order themes to enable explicit linkage to relevant policy domains or regulatory practices. As shown in Figure 1, Step 1 consists of building an inventory of challenges from the interview data. This iterative process provides a focused, yet flexible approach to create an explicit link between on-the-ground challenges and existing policies while preserving the complexity of local conditions. The coding was completed by one researcher, and coding reliability was examined by another researcher, achieving a Mezzich's Kappa of 0.67 (considered suitable for qualitative research; Burla et al. (2008)). To strengthen methodological rigor and transparency, all coding decisions, theme-merging procedures, and policy-linking criteria were documented throughout the analysis to ensure that analytical judgments were traceable and consistently applied.

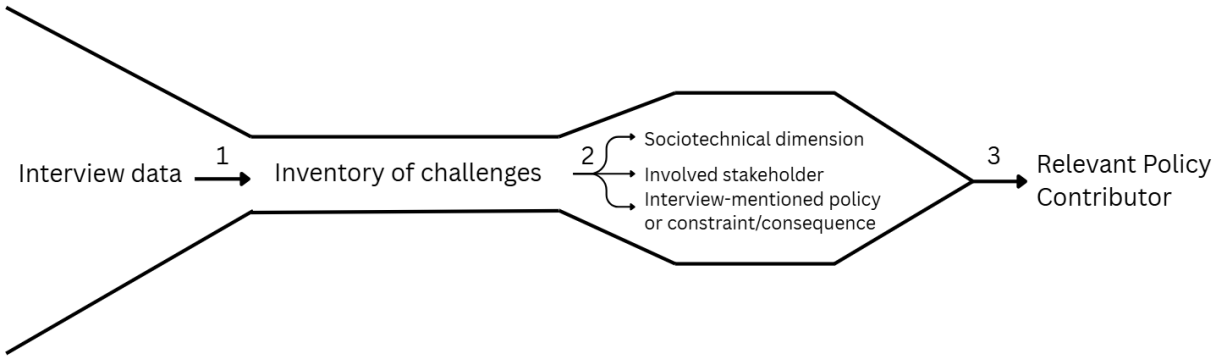

Figure 1. Identification Process of Policy Contributors

After the initial coding stage, the identified challenges were iteratively refined, merged, and condensed into higher-order themes. Step 2 (see Figure 1) consists of examining each higher-order theme through three linked elements: the sociotechnical dimension, the involved stakeholder, and the interview-described constraint, requirement, rule, or consequence affecting practice. These interview-based descriptions served as the starting point for the policy analysis. Step 3 (see Figure 1) then consisted of tracing those interview-described conditions to the broader policy contributor through review of adopted state and federal codes, rules, program requirements, and official agency guidance. The degree of explicit policy discussion in the interview data varied across excerpts based on each interviewee's familiarity with legal frameworks and policies. In some cases, interviewees directly named the relevant agencies, policies, review processes, or regulatory requirements. These cases provided a straightforward starting point for policy tracing. For example, one interviewee stated: "*But one thing that not just our group has advocated for a long time, would be for ADEM [Alabama Department of Environmental Management] to update their toxic pollutant criteria. EPA, every so often, updates toxic pollutant criteria. The idea is that state programs like Alabama's are supposed to implement those during their triennial review process. And we have had multiple cycles of triennial reviews without the implementation of the newest and best toxic pollutant criteria. So, one thing that I would love to see is for ADEM to stay on top of EPA's recommendations and to promptly implement the toxic pollutant criteria as it comes down.*" In this case, Step 2 identifies the relevant stakeholders and the interview-mentioned regulatory condition directly, which makes Step 3 relatively straightforward because the excerpt itself pointed us toward ADEM, EPA guidance, and the triennial review process.

Similarly, some interviewees describe the consequences, burdens, or constraints produced by a policy environment without explicitly naming the policy itself or the entity that enforces it. In those instances, we used the interview-described conditions and contexts to identify the relevant entity with jurisdiction over the described situation. For example, consider the following excerpt: *"The mayor was totally clueless about what was going on, and the clerk had no idea what QuickBooks [accounting software] even was. When [they were] trying to put information, [they] had expenses as revenue, and revenue as expenses. [They were] lost"*. The interviewee does not identify a policy source directly. Instead, it describes weak local administrative and financial

capacity. Another interviewee discussing funding institution's requirements allowed us to draw a parallel between the previous excerpt and the USDA: *"The USDA will accept just computations, year-end computations by third party. Or yearend financial reports that are generated from accounting programs like QuickBooks, for some of their funding that they'll provide."* In addition to our familiarity and experience with the Black Belt and its policies, the two previous excerpts were the starting point for a potential link between the USDA and the limited institutional capacity challenge. Then we examined USDA policies related to capacity development and predevelopment planning grants to determine whether a clear and defensible connection could be established. We develop this point in the discussion section. This process followed strict inclusion criteria and considered only (1) adopted (in-force) policy texts relevant to the governance entity, (2) primary sources (i.e., state administrative code repositories, Code of Federal Regulation (CFR), official agency program pages, official waiver memoranda, etc.). We note that we consider guidance/waivers as in-scope only when issued by the relevant agency and directly governing compliance. Consequently, we included a policy contributor only when a clear and defensible connection could be established between the interview-based description and an adopted policy source. In the Results and Discussion section, we focus on the latter cases—i.e., situations where the interviewee does not point toward a clear policy—as they require a more intricate analysis of interview evidence and policy frameworks. Such situations are of further interest to the study objectives, as we aim to unearth new policy-induced failures as opposed to situations that are already subject of ample advocacy like the toxic pollutant criteria example mentioned above.

Study Limitations. Even though we thrive to enhance study rigor by adhering to the requirements of the COREQ reporting checklist, some limitations must be acknowledged. The present study does not claim definitive causality between individual challenges and specific policy contributors. Infrastructure systems are shaped by multiple overlapping technical, institutional, and contextual factors. Instead, the analysis identifies policy contributors through a structured process that links each challenge to the entity with jurisdiction over the governing rules or conditions. This approach ensures that the resulting policy recommendations are directly aligned with actionable institutional authority, even in the absence of singular causal attribution.

Additionally, although this study focuses on Alabama's Black Belt, the described challenges and proposed policy reforms may be relevant to other limited-resource rural areas—such as rural Appalachia, Texas Colonias, Navajo Nation, and tribal lands—facing similar challenges and infrastructure vulnerabilities. Still, we acknowledge that specific local governance, culture, environment, and policy may affect both the nature of infrastructure challenges and the viability of potential policy reforms. This distinction is especially important because the state policies examined in this study are most directly relevant to Alabama, whereas the federal requirements discussed here apply nationally and may create similar implementation burdens across other limited-resource rural communities.

RESULTS AND DISCUSSION

Results of the inductive thematic analysis yielded four higher-level themes that collectively capture the dominant, recurring challenge patterns in the dataset. It is important to note that, through this process, the researchers still have access to the lower-level codes, which become useful during the policy analysis process to substantiate the findings. Table 1 summarizes the structural challenges identified in this study and the corresponding policy contributors.

Table 1. Thematic Challenges and Corresponding Policy Contributors

#	Thematic Challenge Identified from Interviews	Policy Contributor Identified from Adopted Codes
1	Limited institutional capacity	USDA RD Water & Waste Disposal Predevelopment Planning Grant Requirements (USDA-RD, 2025)
2	Operations and compliance constraints	ADEM Administrative Code, Rule 335-10-1-.04 (ADEM, 2017)
3	Licensing and certification misalignment	ADEM Operator Certification Eligibility (ADEM, 2025); ADEM Administrative Code, Rule 335-10-1-.08 (ADEM, 2004)
4	Project delivery and disincentive structure	EPA SRF/IIJA requirements (AIS/BABA + Davis-Bacon compliance conditions) (US-EPA, 2025c, 2025d); Code of Federal Regulations § 35.10030 American Iron and Steel (NARA, 2025)

Limited Institutional Capacity. Capacity shortages significantly impede the progress of municipalities and local government agencies in securing funding and executing development projects. As one interviewee explained, many small towns rely on part-time employees or a single clerk to manage a wide array of responsibilities: *"We've got some good folks out there, but they're part-time. […] They don't have enough time to devote to this. When I say their staff, well, heck, they really don't have much staff. They have a town clerk, and the counties are a little better off with staff, but when you get to the municipal level, a lot of these small towns, they have a clerk and that's pretty much it."* Other interviewees emphasized the lack of experience and insufficient training for such critical roles, illustrating the downstream effects on municipal operations. For instance, one interviewee described the challenges of poor financial management: *"The mayor was totally clueless about what was going on, and the clerk had no idea what QuickBooks [accounting software] even was. When [they were] trying to put information, [they] had expenses as revenue, and revenue as expenses. [They were] lost."* We identified parallels between these challenges and funding agencies' policy for capacity development grants. For example, although USDA Rural Development supports under-capacity communities (e.g., municipalities with a single administrative clerk) by funding planning and application development, its programs typically require at least 25% of the project costs as matching funds from the applicant or third-party sources, with in-kind contributions excluded from this minimum requirement (USDA-RD, 2025).

As a result, communities facing severe capacity shortages and lacking access to the required matching funds—such as the ones in Alabama's Black Belt—fall between the cracks of these policies: they become trapped in a feedback loop in which capacity is required to secure funding, yet funding is needed to build that same capacity. This disconnect reflects situated practice, where uniform policies fail when their assumptions do not match local soils, household finances, and institutional capacity (Suchman, 2007). In parallel, funding agencies should create and expand programs that explicitly encourage regionalized or consolidated administrative support models, rather than assuming that each municipality can independently meet administrative and compliance requirements. Such programs could support shared grant administrators, regional fiscal agents, or technical intermediaries authorized to manage compliance, reporting, and financial oversight across multiple small communities.

Operations and Compliance Constraints. The shortage of a skilled workforce for operating and maintaining both existing and new decentralized wastewater systems has posed significant challenges for O&M companies and utilities. In response, they have been forced to resort to sub-optimal solutions, such as relying on untrained workers with no O&M experience or requiring qualified operators to travel excessive distances (Oke et al., 2018). An interviewee illustrated this situation, stating: *"Way too often you end up with somebody who's on the school maintenance staff, maintaining the wastewater system."* Such practices, however, routinely conflict with regulatory requirements. Specifically, Alabama Administrative Code Chapter 335-10-1.4(7) mandates that all maintenance activities be conducted by a certified operator, regardless of system type and complexity. At the same time, multiple engineers and system designers interviewed in this study emphasized that some newer decentralized technologies have become sufficiently simple that certain routine maintenance tasks could be safely performed by homeowners. As one interviewee explained, "*The maintenance is, you've got to walk along a basin, or a spreader, to make sure there are no low spots and you're getting channelization. And that's something anyone can do. And that's something a homeowner can fix with a simple shovel*". Here, we do not advocate for abolishing certified-operator requirements; rather, we recommend amending the regulatory code to allow homeowners to conduct manufacturer-specified or designer-approved routine maintenance tasks, while licensed operators transition toward less frequent, oversight-focused inspections and responsibility for complex O&M and compliance. Under current regulations, a licensed operator is required to inspect every "grade I" system (e.g., decentralized systems, constructed wetlands) at least once per week. This requirement places considerable strain on an already workforce-limited system, especially in rural regions where neighboring communities often compete for the same pool of certified operators. As one interviewee described, *"Once you get them [operators] certified, then—all of a sudden—the [neighboring] community that has more dollars might snatch them away from you. You spent all the money training them; now, they're more qualified, and they can go to the next major town to get more money."* The policy recommendation advanced here has the potential to relieve pressure on the existing and future certified operators by reducing the frequency of policy-mandated inspections, while safeguarding system compliance through

structured homeowner involvement for low-risk, routine tasks on systems located on their own properties.

Licensing and Certification Misalignment. The lack of appropriate training and certification emerged as a recurring practice-policy gap. Several interviewees noted the absence of operator certification programs for decentralized wastewater treatment technologies that are tailored to the specific needs of small, rural communities, such as those for effluent sewers. For instance, one interviewee with an operator role explained, "*Since we're not in the business of installing all these [decentralized wastewater technologies], it's very difficult for us to go through all the paperwork to get licensed. […] And with [our state environmental regulatory agency], they really don't have an operator license for it, and what they do really doesn't cover a whole lot of what we actually do [in the field]. So, I wish that whole process was easier.*" We trace this mismatch to the structure of Alabama Department of Environmental Management (ADEM)'s operator certification policy, which is centered on public water and wastewater systems and requires experience at a permitted public facility (ADEM, 2025). Such requirements create a poor fit for practitioners whose work focuses primarily on decentralized systems installed on private properties or utility easements. More broadly, this gap in certification reflects a long-lasting emphasis on regulatory compliance and meeting government-defined targets, rather than developing the practical skills required for addressing specific community needs (Wolf et al., 2006). As a result, employers are left to rely on in-house training—a process that is not only inefficient but also costly for all parties involved. Aspiring workforce invests time and money into certifications that ultimately do not align with the actual demands of their roles, while employers incur additional costs and effort to train recruits who are inadequately prepared. As one interviewee described, *"[When] we find ourselves having to hire, we're measuring what their aptitude is and we're spending a year training them ourselves because they don't…really [have] any skills relevant to what we and what the industry really needs."* This persistent disconnect between employer skill needs and the available certifications is further exacerbated by limited employer involvement in the design of training programs, as well as by credentialing systems that prioritize validation of existing skills rather than preparation for real-world, on-the-job demands of the wastewater sector (Wolf et al., 2006). Updating ADEM's operator certification process to explicitly recognize decentralized roles—through a streamlined decentralized endorsement and technology-specific modules tied to manufacturer-approved installation and O&M tasks—could reduce administrative burden and better align credentials with field realities. Such reforms could be implemented while remaining consistent with the oversight expectations established by the Alabama Department of Public Health for clustered systems managed by wastewater management entities.

Project Delivery and Disincentive Structure. Design engineers with expertise in decentralized wastewater treatment technologies are scarce. As one certified operator puts it, *"I don't think anybody has good expertise in decentralized wastewater [treatment systems]. [We] have theoretical understanding, but is anybody an expert? No, because we don't have a good working*

functional system with substantial research and data [to support it]." Additionally, design engineers and large engineering firms show little interest in small-scale projects, favoring large, centralized plants that offer greater financial gains and public visibility (Elliott et al., 2023). As another interviewee stated, *"Pretty much everybody feels like sewer is not profitable at all. Sewer is where you just run into all sorts of financial mess because it does not make money. It just doesn't. And why would you want to get involved with something that really doesn't make money."* We identify potential policy gaps embedded in major financing pathways that may contribute to this situation (e.g., SRF/EPA-funded work) (US-EPA, 2025c). In these programs, requirements such as American Iron and Steel domestic-content rules (NARA, 2025), Build America, Buy America (BABA) provisions (US-EPA, 2025b), and Davis-Bacon labor standards (US-EPA, 2025d), can make small projects disproportionately paperwork-heavy relative to fee size—reducing their attractiveness to engineering firms. Such requirements may be manageable on multi-billion-dollar projects, but they can become a significant drawback for small community projects where administrative overhead consumes a much larger share of limited local capacity and consultant effort. Existing BABA implementation waivers can reduce burden, but they are typically structured around project cost—for example, through de minimis thresholds expressed as a percentage of total project costs or "small grants" carve-outs (US-EPA, 2025a). In limited-resource rural communities, however, total project costs are often high precisely because infrastructure needs are severe, and applications are frequently bundled across multiple small communities to remain competitive. As a result, cost-based thresholds can exclude the very contexts in which compliance challenges are most acute. A more effective approach would rely on community-based eligibility criteria—triggered by rurality and local market conditions (e.g., supplier scarcity, distance to compliant vendors, and socioeconomic disadvantage)—to ensure that rural recipients and their engineering partners are not repeatedly required to complete burdensome waiver documentation simply to demonstrate material nonavailability.

The lack of interest in decentralized systems is further exacerbated by the tendency of design engineers to approach local wastewater issues as generic, textbook cases, rather than addressing the unique needs of rural communities. For instance, an interviewee describes it as such, *"If the Black Belt had a major large-scale engineering firm attempt to solve the problem, what they [will] end up with is the 60-inch diameter pipe that would transfer all the wastewater to the nearest city. And that's just a horrendous waste of money."* This disconnection between expertise and community needs underscores the need to integrate knowledge related to decentralized wastewater infrastructure typologies and technologies into existing civil engineering curricula. Such industry-academia alignment policies would better equip future engineers to design solutions that are contextually appropriate. For currently practicing design engineers, targeted workshops and training material should be developed to emphasize the importance of integrating community perspectives into infrastructure decisions. Solutions that fail to account for communities' capacity, unique challenges, priorities, and lived experiences are probably at risk of being inefficient, unsustainable, or even counterproductive (Richter, 2018).

CONCLUSION

This study identified parallels between recurring implementation challenges in decentralized wastewater systems in Alabama's Black Belt and specific state and federal policy requirements. Using inductive thematic analysis, we showed how policies such as funding match rules, certification structures, and compliance obligations directly reproduce the capacity and workforce limitations they are intended to address. Finally, limited-resource rural communities are often geographically dispersed and operate within institutional settings where their needs and voices are rarely heard in decision-making processes. This disconnection is especially important because policy constraints intersect with power dynamics among stakeholders who have different priorities, interests, and levels of influence. These imbalances can shape which policy solutions are implemented, delayed, or ignored. Future research should therefore examine how rural communities can gain leverage through governance arrangements, intermediary allies, and stronger representation in wastewater decision-making. To address this gap, ongoing work by the authors applies the Matrix of Alliances and Conflicts: Tactics, Objectives, and Recommendations (MACTOR) analysis to systematically map stakeholder alignments, conflicts, and power relations. Making these relationships more transparent can strengthen future policy development strategies and help prevent policies from being imposed on rural communities without fully addressing their needs.

IMPLICATIONS

This study advances the understanding of how policy design and implementation requirements shape decentralized wastewater management challenges, directly responding to calls for more policy-focused research in the literature (Brooks et al., 2025). By capturing insights from community stakeholders, the study identifies structural challenges in limited-resource rural communities—such as those in Alabama's Black Belt. It also traces how these challenges are produced or reinforced by specific federal and state policy conditions. In doing so, the study gives policymakers a clearer view of how rural communities fall between the cracks of existing programs, where support is formally available but practically inaccessible. It also identifies policy alternatives that can begin to fill those cracks, including funding match requirements, operator certification rules, and compliance obligations tied to federally assisted projects. These findings emphasize the need for targeted policy revisions and governance adjustments that reduce administrative burden while preserving accountability and system performance. These implications span both immediate adjustments within existing regulatory frameworks and broader structural changes to funding and governance arrangements. Building on this understanding, the study links structural challenges to actionable policy levers, including updated certification pathways for decentralized contexts, right-sized compliance expectations for routine tasks, and funding and program structures that do not systematically disadvantage small or under-capacity communities. Addressing these policy drivers can improve implementation feasibility and long-term system performance, thereby supporting more effective decentralized wastewater management in limited-resource rural communities. Ultimately, this study contributes to

wastewater management and governance by challenging a system that blames rural communities and frontline professionals for failures produced by policy structures they did not design, do not control, and cannot overcome alone.

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AI STATEMENT

Generative AI tools were not used to develop the structure, methodology, analysis, interpretation, or arguments of this manuscript. AI assistance was limited to language editing for grammar, clarity, and readability.

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