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Descriptive Study of Infiltration Well Design and Utilization in Sleman Regency, Special Region of Yogyakarta

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ABSTRACT

In Indonesia, household-scale infiltration wells serve dual functions: managing rainwater and acting as secondary treatment systems for domestic wastewater from septic tanks. These roles require distinct designs, particularly in the arrangement and thickness of filter media. According to Indonesian technical standards (SNI – Standar Nasional Indonesia), wells designed for septic tanks use thicker, multi-layered filters that occupy most of the well's volume, while rainwater wells typically feature only a thin filter at the base. This difference reflects the higher pollutant levels in septic tank effluent compared to rainwater. Direct interviews with housing contractors in Sleman Regency, involving 836 household samples, revealed that all households repurposed rainwater infiltration well designs for managing domestic wastewater. Such practices deviate from intended design standards, raising concerns about the effectiveness of the filtration systems in these wells for contaminant removal and their potential contribution to groundwater pollution. The study further examined correlations between population density, soil characteristics, and the design and usage patterns of infiltration wells. In densely populated areas, more complex systems are often employed to manage wastewater and rainwater efficiently in limited spaces. In contrast, simpler systems are more common in less populated areas. Additionally, regions with clay-rich soils require larger wells to accommodate slower infiltration rates, while areas with sandy soils need smaller wells due to higher infiltration rates. These findings emphasize the importance of aligning infiltration well designs with both their intended purposes and local environmental conditions. Properly designed systems that manage wastewater and rainwater separately can reduce the risk of groundwater contamination, promoting more sustainable water management practices.

1. Introduction

Infiltration wells are infrastructure designed to capture and enhance water absorption from surface sources such as rainfall, irrigation, or river flow into the ground. These wells are commonly used for aquifer recharge [1], water treatment, and pollution reduction [2]. In Indonesia, two key technical standards govern the construction of infiltration wells: SNI 8456:2017 for rainwater wells and SNI 2398:2017 for septic tank effluent wells. The primary difference between these standards is the thickness and arrangement of filtration, with septic effluent wells requiring more robust filters to manage higher pollutant levels [3] [4].

Several local governments in Indonesia, including Sleman Regency in the Special Region of Yogyakarta, have adopted regulations for groundwater conservation through the use of rainwater infiltration wells. While not all regions have specific regulations, many require their installation as part of the Building Permit process. Sleman Regency mandates the installation of both rainwater and wastewater infiltration wells under Sleman Regency Regulation No. 49 of 2012 [5]. This regulation aims to maximize the use of open spaces, though it lacks details on filter specifications. As the most populous area in the Special Region of Yogyakarta, Sleman faces increased water demand and wastewater production due to migration and its status as a part of student and tourist hub [6]. This raises concerns about groundwater contamination if wastewater is improperly managed [7] [8].

Previous studies indicate that domestic wastewater significantly contributes to groundwater contamination in Sleman. For instance, research along the Code and Winongo rivers found that densely populated areas (>60%)

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with untreated wastewater disposal increased contamination risks [9]. Moreover, observations of groundwater quality in Sinduadi Village revealed that phosphate and pH levels exceeded permissible limits due to wastewater discharge from laundry businesses, much of which was disposed of in infiltration wells [10]. Additionally, local sanitation systems contributed to nitrate and coliform contamination, particularly in the Depok and Sleman subdistricts [11]. The region's porous volcanic lithology and soil types, such as regosol and lithosol, further facilitate the infiltration and dispersion of contaminants.

This study aims to identify and analyze the design and use of infiltration wells commonly employed in Sleman Regency for managing both rainwater runoff and domestic wastewater. Additionally, it will explore the extent to which these wells are repurposed and provide recommendations for improving groundwater management practices.

2. Methods

This research gathered insights through direct interviews with contractors engaged in residential construction projects across Sleman Regency, the Special Region of Yogyakarta. Covering 574.82 km² with 17 subdistricts (kapanewon) and 86 villages (kalurahan), Sleman is located between 110° 33′ 00″–110° 13′ 00″ East Longitude and 7° 34′ 51″–7° 47′ 30″ South Latitude [12], can be seen in Figure 1. While urbanization has intensified in certain areas, the region’s diverse topography underscores the need for sustainable water management to mitigate floods and preserve groundwater.

The focus of this study was on residential houses that implement infiltration wells for managing rainwater runoff and domestic wastewater. The methodology was specifically tailored to capture practical applications and contextual challenges, thereby providing a robust foundation for subsequent analysis and interpretation.

A descriptive study approach was employed to systematically analyze and summarize data patterns concerning the utilization and design of infiltration wells in Sleman Regency. Descriptive statistics, including measures of central tendency such as mean, mode, and median, were calculated to provide a clear summary of the data. These findings were further contextualized by integrating geographical, social, and environmental variables. This approach is particularly suited for identifying data trends and patterns without requiring advanced statistical modeling [16].

Data were gathered through field interviews with local contractors, offering qualitative insights, and supplemented by quantitative data sourced from official reports, such as those provided by regency statistics office and other government agencies. Statistical analyses were conducted using Microsoft Excel to calculate central tendency measures and assess variability, ensuring a comprehensive summary of key data points and identification of underlying patterns. This integration of qualitative and quantitative methods ensured the robustness of the analysis.

By combining numerical data with contextual information, the study aimed to uncover patterns and relationships that provide insights into the implementation of infiltration wells across diverse regional and socio-environmental contexts. This methodological framework facilitates a more nuanced interpretation, allowing findings to go beyond numerical summaries and contribute to a deeper understanding of factors influencing infiltration well practices. This integrated approach enhances the comprehensiveness and applicability of research findings [17].

2.1 Population and Sample Size Determi nation

Prior to data collection, the minimum required sample size was determined to ensure adequate representation of the population. According to Department of Public Housing and Settlement Areas of Sleman Regency, there were 309,071 residential units in 2023 [13]. Meanwhile, data from Sleman Regency Statistics Office estimated 385,022 households, assuming one household equates to one residential unit [14]. To maximize representativeness, the higher figure of 385,022 units was adopted as the population base, ensuring a broader spectrum of potential infiltration well users was encompassed. This decision aligns with the study's objective of reflecting regional housing demands and associated infrastructure needs, thereby enhancing the robustness and validity of the findings.

The minimum sample size was calculated using Slovin’s formula, Krejcie-Morgan’s table, and Cochran’s formula, applying a margin of error (d) of 5% and a confidence level of 95%. These calculations yielded minimum sample sizes of 400 (Slovin), 384 (Krejcie-Morgan), and 384 (Cochran). While Krejcie & Morgan’s formula is commonly used in research involving large populations to ensure representative sample sizes and high accuracy, this study adopted Slovin’s formula, resulting in a minimum sample size of 400 residential units (the highest sample size) to ensure optimal representativeness, inclusivity, and statistical precision. This sample was then distributed proportionally across the 17 subdistricts in Sleman Regency based on the number of households in each subdistrict. Stratified random sampling was used to ensure balanced representation across the region, allowing the findings to be generalized to the broader population.

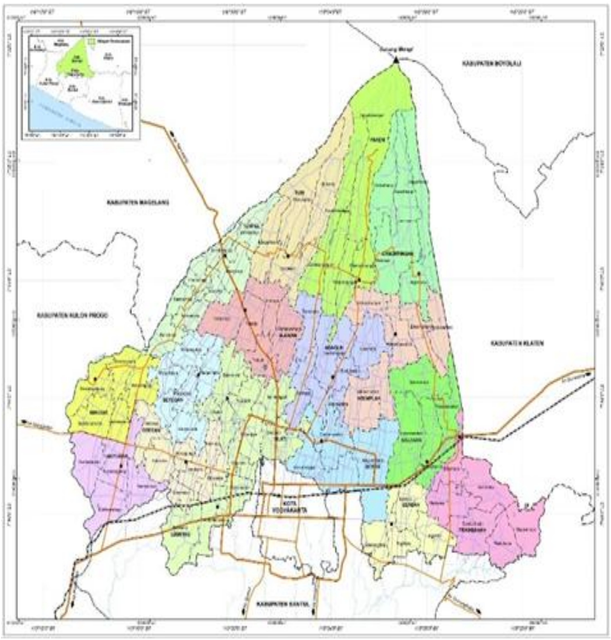

Figure 1. Area of Study (Sleman Regency) [15]

2.2 Data Collection

Field data collection was conducted over a 20-day period, from July 1 to July 20, 2024. The study employed a combination of stratified random sampling and snowball sampling techniques. In addition to randomly selecting respondents within each subdistrict, interviewees were asked to recommend other contractors, builders, or foremen who could serve as potential respondents for subsequent interviews. This approach efficiently expanded the data scope while maintaining the structured sampling framework. Direct interviews were conducted face-to-face at construction sites whenever possible, or via telephone to accommodate respondents unable to meet in person.

The interviews consisted of 54 structured questions covering respondent demographics and detailed technical aspects of infiltration wells. Key areas of inquiry included well dimensions, utilization practices, filter types, and the number of wells constructed or currently under development. Respondents were encouraged to provide data on multiple residential units, encompassing both ongoing and completed projects across various subdistricts, see Figure 2. This approach yielded a total of 28 respondents contributing data on 836 residential units—more than double the minimum required sample size. The surplus data improved the reliability of the findings, reduced the margin of error, and enhanced the capacity to capture inter-subdistrict and inter-contractor variations.

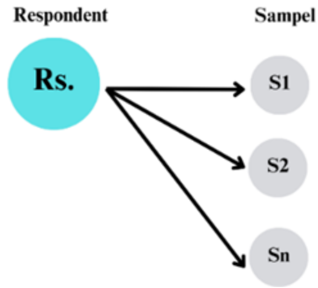

Figure 2. Types of data samples

3. Result and Discussion

3.1 Responden Profile

Respondent information included company addresses, business entity types, years of experience, and the number of completed projects. To ensure confidentiality and encourage open communication, specific company names and details were excluded from the interviews. Most respondents (71%) were contractors based in the Special Region of Yogyakarta, with 16 from Sleman Regency, 3 from Bantul, and 1 from Yogyakarta City. The remaining respondents were from Central Java, comprising 6 from Klaten and 2 from Magelang.

Only 25% of respondents operated under formal business entities, such as limited partnerships (Commanditaire Vennootschap, CV) or limited liability companies (Perseroan Terbatas, PT), while the majority (75%) were Freelance foremen without formal registration. Many respondents cited tax and administrative obligations as key reasons for avoiding formal business structures, preferring the flexibility and higher profit margins offered by informal arrangements.

Respondents' work experience ranged from 2009 to 2024 and was categorized into three groups based on the duration of their involvement in the field Table 1: 0–5 years (68%, 337 projects), 6–10 years (14%, 131 projects), and 11–15 years (18%, 368 projects). This classification highlights the variation in professional experience and project involvement among respondents.

A clear relationship was observed between years of experience and the volume of projects handled. Respondents with 0–5 years of experience managed an average of 17.74 projects, those with 6–10 years averaged 32.75 projects, and respondents with 11–15 years of experience handled 73.6 projects on average. This trend, detailed in Table 1, underscores how increased experience leads to greater project engagement, reflecting enhanced skills and broader opportunities over time [18] [19].

Table 1. Respondents' Experience and Participation in Residential Projects (2009–2024)

Experience	Number of respondents	Number of projects (sample)	Project-to-respondent ratio
0-5 years	19	337	17.74
6-10 years	4	131	32.75
11-15 years	5	368	73.60
Total:	28	836	-

3.2 Sample Distribution

To assess the distribution of samples across Sleman, the districts were categorized into four regions based on geographical proximity: West Sleman, East Sleman, Central Sleman, and North Sleman, consistent with the district's spatial planning for 2021-2043. West Sleman comprises subdistricts such as Godean, Moyudan, Minggir, and Seyegan [20]. East Sleman includes Prambanan, Berbah, Kalasan, and Ngemplak [21]. Central Sleman covers Depok, Mlati, Sleman, and Gamping [22]. Lastly, North Sleman encompasses Pakem, Turi, Tempel, and Cangkringan. See Figure 3.

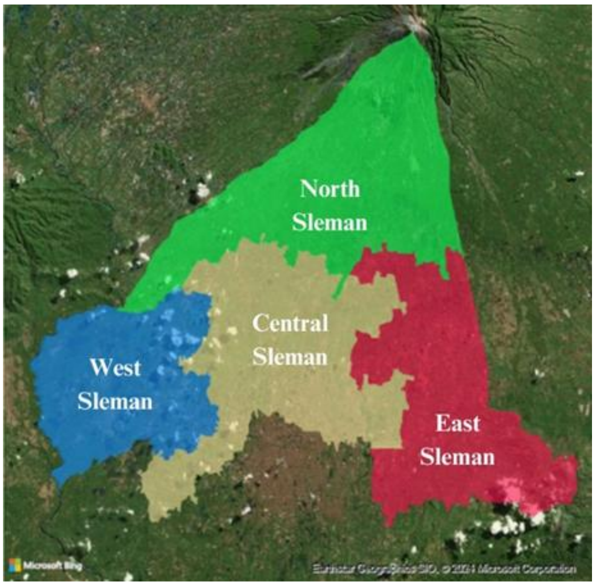

Figure 3. Regional classification of Sleman Regency

In the subsequent section, Figure 4 presents the comparison of minimum sample sizes, actual samples, and percentage increases across these regions from 2009 to 2024. A 0% increase, where actual samples match the minimum, indicates stability and homogeneity, with limited variation in residential construction. In contrast, a percentage increase greater than 0% reflects diversity and more complex development dynamics [23].

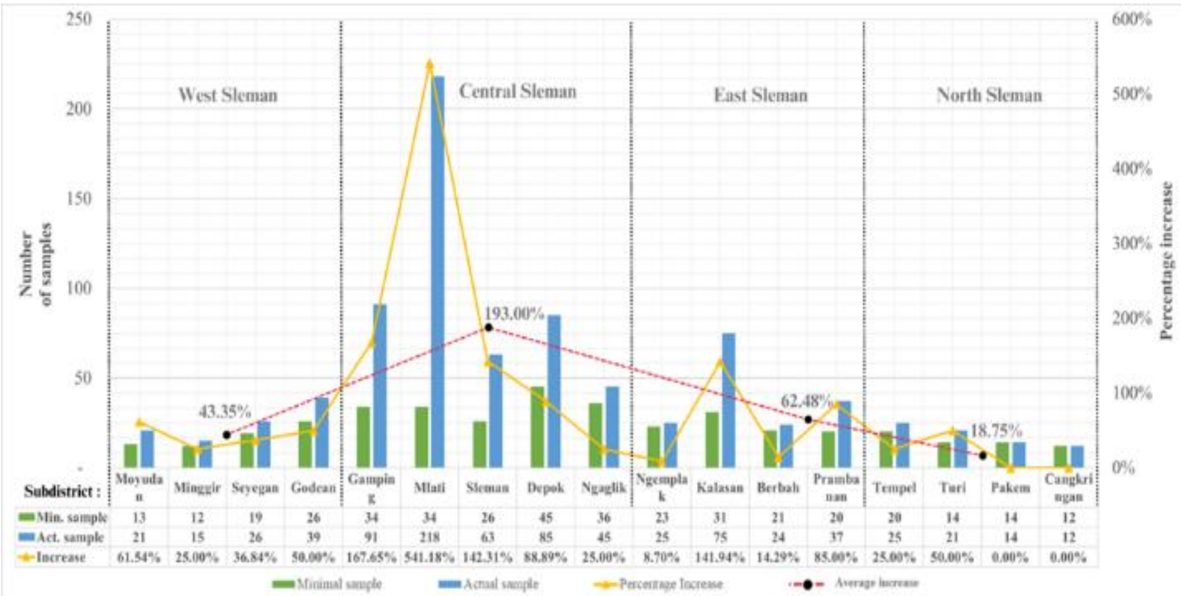

Figure 4. Comparison of sample sizes and percentage increases

Central Sleman exhibited the highest sample increase, with Mlati showing a 541.18% rise and an average increase of 193.00%. East Sleman showed a significant rise of 141.94% in Kalasan, with an average increase of 62.48%. West Sleman reported a 61.54% rise in Moyudan, with an average of 43.35%. North Sleman experienced a 50% increase in Turi, with an average of 18.75%. These findings underscore significant regional variation in residential projects involving infiltration wells, with the highest growth observed in Central Sleman and East Sleman. In contrast, the more moderate increases in West Sleman and North Sleman suggest relatively stable development patterns.

The observed trends generally align with household growth data in Sleman over the past 15 years. East Sleman and Central Sleman experienced growth rates exceeding 3%, with rates of 3.89% and 3.38%, respectively. In contrast, West Sleman and North Sleman saw more moderate growth rates of 2.96% and 2.21%. These figures suggest a clear correlation between household growth and residential development dynamics. However, as shown in Figure 5, a few exceptions exist. For instance, although Central Sleman exhibited higher sample increases than East Sleman, household growth in Central Sleman was lower than that in East Sleman. This discrepancy suggests that sample increases do not necessarily correlate with household growth, as the study specifically focuses on homes with infiltration wells, while household growth data encompasses all types of residences, irrespective of drainage systems

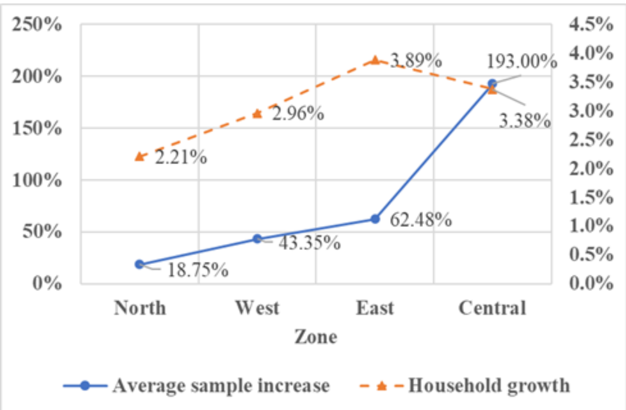

Figure 5. Comparison of average sample increase and household growth in Sleman Over the Past 15 Years

Household growth and the subsequent rise in residential construction significantly affect local hydrological systems, particularly through changes in land cover. The expansion of impervious surfaces reduces natural groundwater recharge and increases surface runoff, as widely documented [24] [25]. Central Sleman, particularly Mlati, strategically located near Yogyakarta's capital, exemplifies this trend as a result of continuous urban expansion [26]. The rapid development in this area demands efficient water management to address drainage and flooding challenges. The adoption of infiltration wells mitigates these issues by enhancing groundwater infiltration and supporting sustainable water management. This aligns with global findings that highlight the critical role of infrastructure like infiltration wells in mitigating environmental impacts while promoting sustainability in rapidly urbanizing regions [27].

3.3 Utilization Patterns of Infiltration Wells

The interviews revealed five common patterns of infiltration well utilization for managing domestic wastewater and rainwater, as shown in Figure 6.

Pattern 1 involves three wells, each serving distinct types of wastewaters: rainwater, effluent from septic tanks (ST), and greywater (bathroom and kitchen wastewater). Pattern 2, similar to Pattern 1, separates the greywater before directing it into the wells—bathroom wastewater is mixed with rainwater, while kitchen wastewater is diverted into a separate well. Pattern 3 uses two wells, one for septic tank effluent and greywater, with rainwater discharged directly to the surface. Patterns 4 and 5 each feature a single well; in Pattern 4, all wastewater types (rainwater, septic effluent, and greywater) are combined in one well, while in Pattern 5, only septic effluent and greywater are collected, with rainwater discharged to the surface.

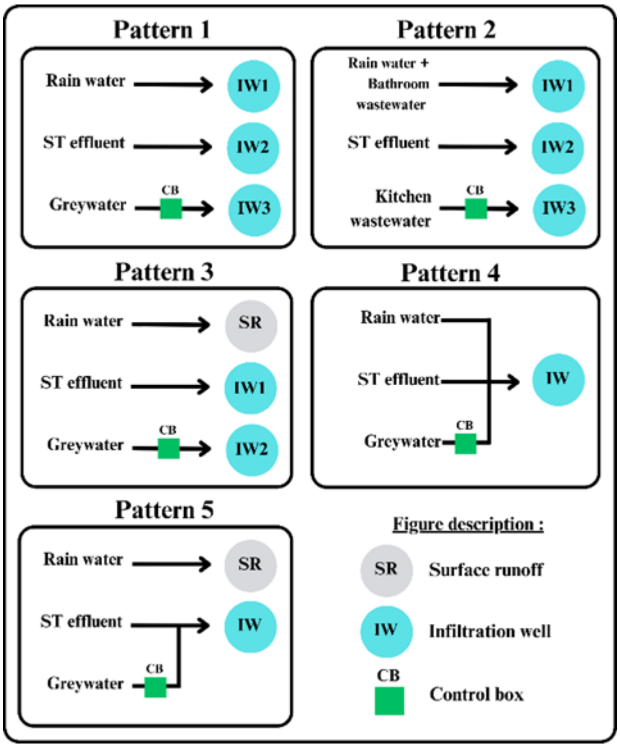

Figure 6. Common patterns of infiltration well utilization in Sleman Regency

A key feature in all patterns is the control box, which collects greywater or kitchen wastewater before it enters the infiltration well. These boxes, typically made from brick or concrete blocks, are cube-shaped (30–50 cm sides) or constructed using an 80 cm diameter concrete ring. The boxes are equipped with mesh filters at the inlet and outlet to capture solids. According to most respondents, the control boxes help regulate wastewater flow, facilitate maintenance, and prevent solids from entering the wells.

3.3.1 Spatial Distribution of Infiltration Well Utilization Patterns

Infiltration well utilization in Sleman Regency is predominantly characterized by Pattern 1, representing 67% of the samples. This is followed by Pattern 3 (13%), Pattern 4 (12%), and smaller proportions for Patterns 2 and 5, at 5% and 3%, respectively. To explore the spatial distribution of these patterns, the districts are grouped into four regions—Central, East, West, and North Sleman—based on geographic proximity, as shown in Figure 7.

Although Pattern 1 dominates most of Sleman, significant variations in infiltration well utilization are shaped by socio-demographic and geographical characteristics. High-density areas like Central Sleman (1,037 households/km²), see Figure 8, implement intricate systems for wastewater management due to limited land availability. East Sleman (695 households/km²) also adopts relatively advanced patterns, though not as complex as in Central Sleman. In contrast, West Sleman (627 households/km²) uses moderately complex patterns, reflecting its intermediate population density. North Sleman (363 households/km²) relies predominantly on simpler patterns, reflecting the availability of larger land areas and lower infrastructure demands.

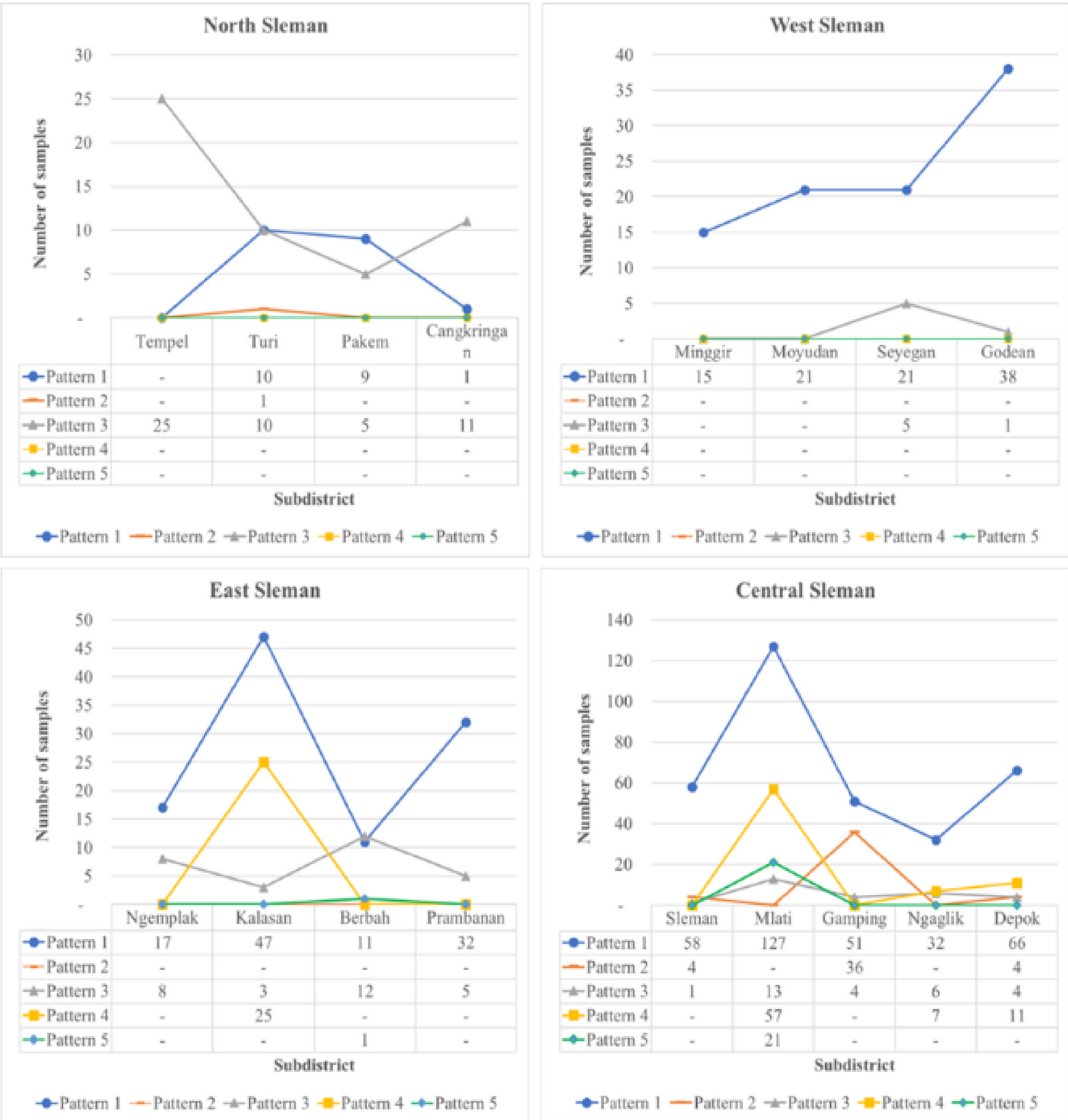

Figure 7. Distribution patterns of infiltration well utilization in Sleman Regency

These findings support existing theories that densely populated regions face greater pressures to mitigate environmental pollution and optimize water resources [28] [29], and that socio-demographic and geographical factors play a crucial role in shaping water resource management strategies [30] [31] [32].

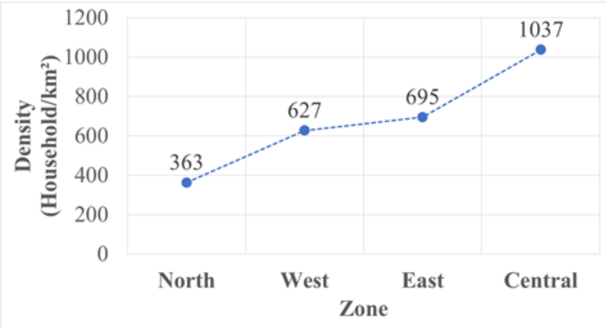

Figure 8. Household Density Across Zones in Sleman Regency

3.3.2 Soil Characteristics and Elevation Effects on Infiltration Well Pattern

Sleman Regency's infiltration well utilization is strongly influenced by regosol soil, which covers 81.95% of the area. This volcanic soil, with a coarse texture mixed with sand, has good water absorption properties [33] [34]. However, other soil types, such as grumusol, cambisol, mediterranean, and lithosol, show varying water absorption capacities, resulting in different infiltration well usage patterns across sub-districts.

The impact of regosol and varying elevation (ranging from <100 m to >1000 m above sea level) is significant in shaping these patterns. In higher regions (above 500 m) like Tempel, Turi, Pakem, and Cangkringan (North Sleman), Pattern 3 predominates, where rainwater is directly absorbed into the ground due to the porous, rocky regosol near Mount Merapi [35].

In contrast, regions between 100 m and 500 m, such as West, Central, and East Sleman, typically use Pattern 1, where rainwater, septic tank effluents, and greywater are collected in infiltration wells. These areas prioritize structured wastewater management, as the soil, while sandy, does not absorb water as efficiently as in the northern regions.

The utilization of infiltration wells in Sleman is influenced by both soil characteristics and elevation. In higher areas, coarse regosol allows for direct absorption, while in lower areas, where regosol has reduced absorption capacity, wells are used more to manage rainwater and wastewater. These factors demonstrate the importance of local physical and geographical conditions in shaping sustainable water resource management strategies.

3.4. Design of Infiltration Wells

The majority of respondents (27 out of 28) designed infiltration wells without detailed drawings, relying on experience or previous practices, while only one used specific technical guidelines or regulations. This underscores the absence of widely adopted standards among practitioners for determining dimensions, materials, filters, and other technical aspects in infiltration well construction in Sleman Regency.

3.4.1. Dimensions and Materials of Infiltration Wells

In practice, contractors often rely on habits and experience, consistently constructing infiltration wells above the groundwater in Table 2. This positioning is critical for optimizing infiltration, as it allows water to first be absorbed by surrounding soil layers before reaching the groundwater, reducing contamination risks and enhancing efficiency [36] [37].

Table 2. Average groundwater table depth in Sleman Regency [38]

Year	Average Groundwater Table Depth (m)	
	Dry Season	Rainy Season
2018	5.96	7.97
2019	5.80	8.07
2020	5.64	7.51
2021	5.56	7.27
2022	6.07	6.28

Based on Figure 9, the most common well depth is 4 meters, accounting for 47.1% of samples, followed by 3 meters at 24.5%. Most wells have an 80 cm diameter (86.2%), with 100 cm used in 13.8% of samples. Depths typically increase in 0.5-meter increments, reflecting the use of concrete rings with a standard segment height of 0.5 meters. These dimensions are widely available in Sleman Regency, making them the preferred choice. Although smaller diameters, such as 60 cm or below, exist, they are rarely used. To enhance functionality, the sides of infiltration wells are often made impermeable, directing water downward rather than laterally, thus maximizing vertical infiltration.

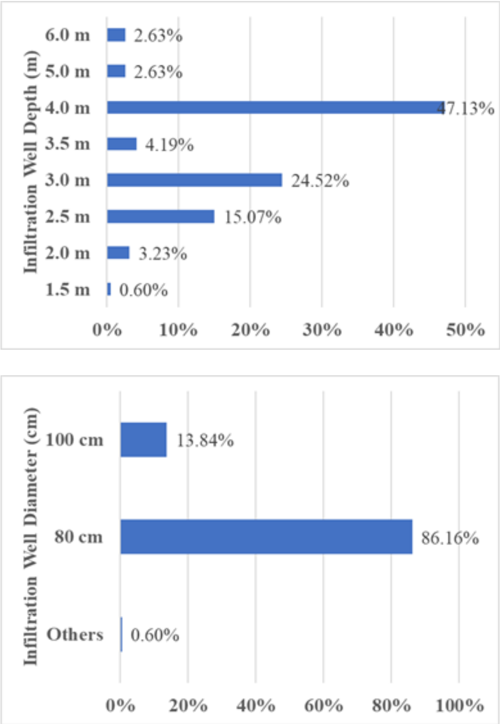

Figure 9. Percentage of infiltration well depth and diameter samples

Precast concrete rings, Figure 10, are preferred for their durability, structural stability, and resilience to diverse soil and weather conditions. Their circular shape evenly distributes soil pressure, ensuring long-term reliability. Standard sizes also simplify installation, allowing contractors to easily select materials suitable for project needs.

Figure 10. Precast concrete ring installation

The distribution of infiltration well volumes in Sleman Regency correlates with soil type, particularly clay-rich soils like grumusol, Cambisol, and Mediterranean soils, which affect water absorption capacity. The analysis spans four regions can be seen in Figure 11, each showing variations in soil type and well volume.

Infiltration wells can be classified into two groups based on capacity. West Sleman and Central Sleman have average well volumes exceeding 3 m³, while North Sleman and East Sleman have volumes below 3 m³. This distinction reflects soil characteristics that influence runoff management.

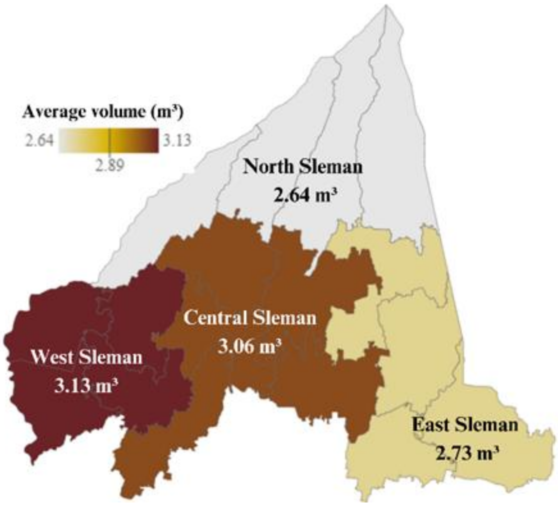

Figure 11. Distribution of infiltration well volume

West and Central Sleman have higher clay content as shown in Figure 12, requiring larger well volumes. In Central Sleman, the average well volume is 3.07 m³, with clay soils covering 29.41% of the total clay area in Sleman Regency. Clay slows infiltration, necessitating larger wells. West Sleman's average well volume is 3.13 m³, with the highest clay content at 51.68%, further reducing infiltration. In contrast, North and East Sleman feature sandy soils with lower well volumes. North Sleman's average well volume is 2.64 m³, with no clay present, promoting faster infiltration. East Sleman has an average volume of 2.73 m³, with 18.91% clay, allowing for more efficient infiltration than in the West and Central regions.

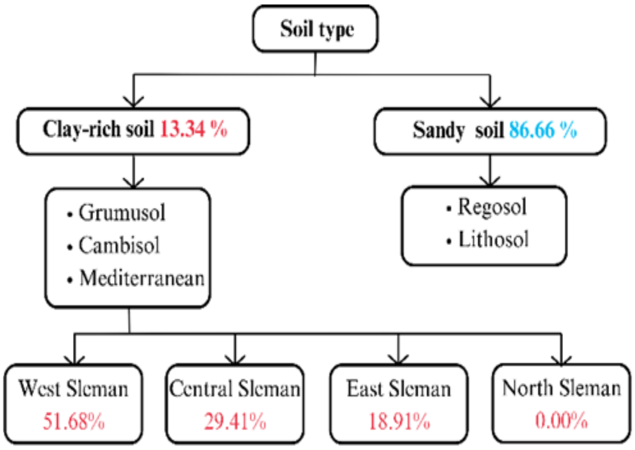

Figure 12. Proportion of soil types in Sleman Regency [39]

Overall, regions with higher clay content require larger wells to manage slower infiltration rates, while sandy soils allow for faster water penetration and smaller well volumes [40] [41].

3.4.2 Filter of Infiltration Wells

Filter Configuration

The use of filtration systems in infiltration wells indicates that 82.54% of the samples studied incorporated filters, while 17.46% did not. The study identified 11 different filter configurations, ranging from one to three layers, with each layer's thickness varying between 10 to 20 cm, resulting in a total filter thickness of 15 to 45 cm as shown in Figure 13.

The most common filter arrangement, comprising palm fiber, sieved gravel, and sand, with each layer 10 cm thick, accounted for 36.67% of the samples. Specifically, sieved gravel and palm fiber emerged as the dominant materials, representing 62.75% and 54.06% of the samples, respectively. Sieved gravel is typically placed in the middle layer of a three-layer arrangement and is in direct contact with the soil in the first and second layers, while palm fiber is generally positioned as the top layer.

The variation in filter configurations and thicknesses indicates a lack of standardization among contractors. Interviews revealed that most infiltration wells were designed based on personal experience and previous projects, underscoring the need for formal guidelines or standards to enhance consistency and improve runoff management effectiveness.

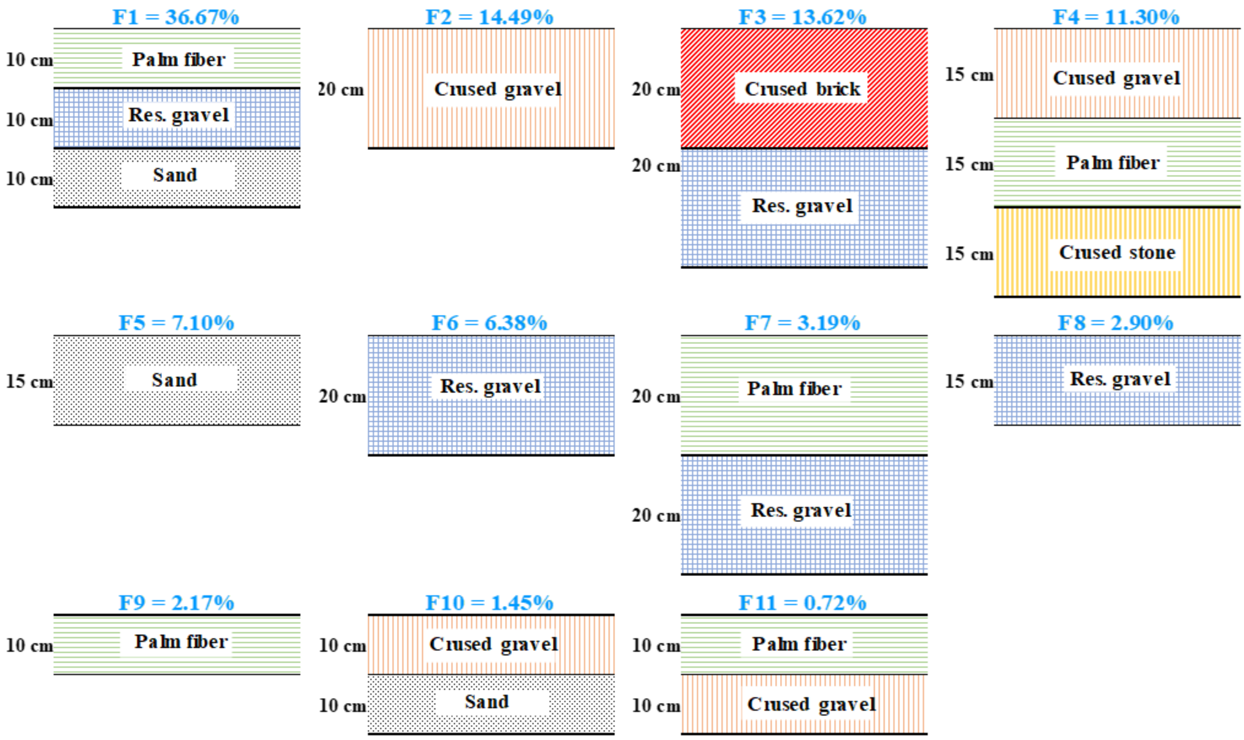

Figure 13. Filter configuration in infiltration wells

Filter Material

Filter materials used in infiltration wells can be categorized into three main types: coarse aggregates, fine aggregates, and natural fibers. Coarse aggregates include crushed gravel, residual screened gravel, crushed stone and crushed brick; fine aggregates are represented by sand; and natural fibers consist of palm fiber.

Residual screened gravel is the most commonly utilized coarse aggregate. Derived from the manual screening of sand, it comprises particles larger than 1 cm (passing through a 1 cm sieve). Its use emphasizes resource optimization by repurposing byproducts that are otherwise underutilized.

Crushed gravel and stone exhibit different characteristics. Crushed gravel, mechanically produced, has uniform particle sizes ranging from 2–20 mm, while crushed stone offers a broader size range (15–25 cm), making it suitable for applications requiring better interlocking properties.

Despite its limited use, crushed brick is sometimes employed as an alternative coarse aggregate, promoting material reuse and reducing construction waste.

Fine aggregates predominantly consist of sand extracted from quarries near Mount Merapi, preferred for its cost-effectiveness over sand from the Progo River. Meanwhile, natural fibers like palm fiber, sourced from Arenga pinnata palm fronds, are widely used due to their eco-friendly properties and economic value. As a result, palm fiber is the second most frequently employed filter material after residual screened gravel.

Correlation between Soil Types and Filter Usage

The relationship between soil characteristics and filter usage in infiltration wells was analyzed through the percentage of wells without filters, filter volumes, and clay soil distribution.

As shown in Figure 14, in North Sleman, 47.02% of wells lack filters, and the average filter volume is the smallest (3.24%). The absence of clay or water-retentive soils indicates naturally high permeability, reducing the necessity for additional filtration. In contrast, West Sleman, with the highest clay soil proportion (51.68%), has only 9.4% of wells without filters, and the filter-to-well volume ratio is the largest (8.79%). This emphasizes the critical role of filters in areas with low-permeability soils to facilitate infiltration and prevent clogging. Central Sleman, with 29.41% clay soil, shows balanced filter usage. Here, 13.95% of wells lack filters, with a filter volume of 6.98%. In East Sleman, where clay soil accounts for 18.91%, filter implementation is less consistent; 22.71% of wells lack filters despite relatively supportive soil conditions.

Overall, regions with higher clay content, such as West and Central Sleman, generally employ larger filter volumes. This pattern underscores the significance of filters in enhancing water infiltration and ensuring efficient system functionality in areas with reduced natural permeability [42].

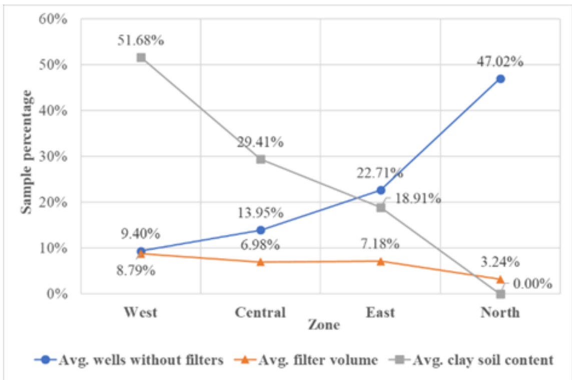

Figure 14. Distribution of the percentage of wells without filters, filter volume, and clay Soil content

3.4.3. Distance of Infiltration Wells to Clean Water Sources

The distribution of infiltration wells in relation to clean water sources (bore wells or dug wells) reveals that 36.72% of the wells are located within a 6 to 8-meter range, 39.11% are between 9 and 11 meters, 13.04% fall within 12 to 14 meters, and 11.12% are situated 15 meters or more away. The highest concentration of wells is found within the 6 to 11-meter range, highlighting a general trend of proximity to water sources across the region.

These distance patterns show a clear correlation with household density in Sleman Regency in Table 3. In areas with lower density, such as North Sleman (363 households/km²), longer distances (≥9 meters) are generally maintained between wells and water sources. The availability of larger land areas in these regions facilitates better spatial planning and effective separation to protect water quality. In contrast, higher-density areas like Central Sleman (1037 households /km²) face land constraints, leading to wells being placed closer to water sources. In these regions, the majority of wells are situated within 6-8 meters of clean water sources, which increases the risk of contamination, particularly in areas with suboptimal soil or water management.

A similar trend is seen in West Sleman (627 households/km²) and East Sleman (695 households /km²), where most sub-districts maintain a distance of 9-11 meters, although West Sleman includes some areas where wells are located ≥15 meters away from clean water sources. These findings underscore the challenges of spatial planning in high-density regions and emphasize the need for strategic measures to protect water quality and public health [43] [44] [45].

Table 3. Common distances between infiltration wells and clean water sources

West Sleman		East Sleman	
Subdistrict	Distance	Subdistrict	Distance
Moyudan	9 - 11 m	Berbah	9 - 11 m
Minggir	12 - 14 m	Prambanan	12 - 14 m
Seyegan	6 - 8 m	Kalasan	6 - 8 m
Godean	9 - 11 m	Ngemplak	9 - 11 m
Central Sleman		**North Sleman**	
Subdistrict	Distance	Subdistrict	Distance
Gamping	6 - 8 m	Tempel	9 - 11 m
Mlati	6 - 8 m	Turi	12 - 14 m
Depok	6 - 8 m	Pakem	6 - 8 m
Ngaglik	9 - 11 m	Cangkringan	9 - 11 m
Sleman	≥ 15 m		

3.5. General Overview of Infiltration Wells in Sleman Regency

Contractors in Sleman Regency typically design infiltration wells based on prior experience, using precast concrete rings with an 80 cm diameter, a 4-meter depth, and impermeable walls, along with a 30 cm filter layer of palm fiber, residual screened gravel, and sand. The wells are placed 9–11 meters from clean water sources, in line with SNI 8456:2017, the technical standard for rainwater infiltration wells in Indonesia, see Figure 15. These wells, initially designed for rainwater management, are also repurposed for greywater and septic tank wastewater, with three wells typically assigned per household for each type of waste. While this dual-purpose design addresses both water and wastewater, it raises concerns about its potential environmental impact, particularly in terms of water quality and ecosystem health.

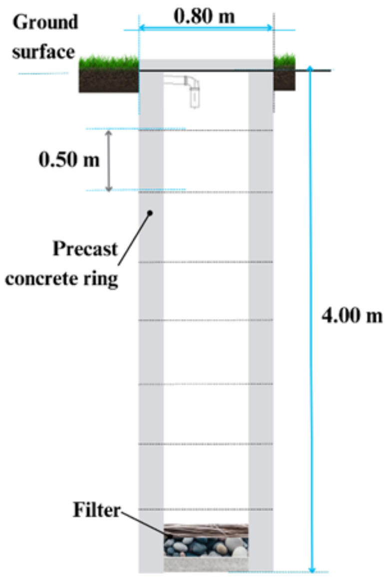

Figure 15. Typical design of infiltration wells in Sleman Regency

Conclusion

The design of infiltration wells in Sleman Regency reflects socio-demographic and geographical factors. High-density areas like Central and East Sleman, where land availability is constrained, require more complex systems to effectively manage rainwater runoff and wastewater. Conversely, North and West Sleman, characterized by lower population densities and more available land, implement simpler systems. These variations in system complexity are further influenced by soil characteristics; regions with high clay content, such as West and Central Sleman, require larger well volumes and thicker filters to compensate for slower infiltration rates. In contrast, sandy soils in North and East Sleman allow for smaller wells and thinner filters, facilitating faster water absorption due to higher permeability.

In North Sleman, the lowest-density area, wells are generally placed at least nine meters from water sources to maintain water quality. In contrast, in other higher-density areas, wells are positioned closer to water sources, often within less than nine meters, to maximize the available land. This proximity increases the risk of contamination, particularly in areas with suboptimal soil or water management conditions.

This issue is further exacerbated by the design practices for infiltration wells commonly constructed by contractors in Sleman. These wells are primarily designed based on personal experience and intended for rainwater management. However, these designs are universally repurposed for the direct treatment of domestic wastewater, without undergoing the necessary pre-treatment processes. Additionally, there are no specific infiltration wells implemented exclusively for domestic wastewater treatment. This improper repurposing of well designs significantly heightens the potential environmental risks, as the filtration systems may not be adequately equipped to handle the distinct characteristics and contamination levels of domestic wastewater compared to rainwater.

To address the challenges related to infiltration wells in Sleman Regency, it is crucial to establish more comprehensive and detailed regulations that ensure clear standards, effective monitoring, and consistent implementation throughout the region. These regulations should align with the technical specifications set out in the SNI, ensuring the quality and suitability of both rainwater and wastewater infiltration well management. Furthermore, enhancing outreach and education efforts for contractors and the public on proper well usage is essential to safeguard environmental quality. These initiatives will promote awareness and encourage adherence to best practices, supporting sustainable water management in the region.

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