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Investigation of Soil Infiltration Rate at Universiti Tun Hussein Onn Malaysia

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Abstract

Urbanization challenges the natural water cycle, leading to increased runoff surface and elevated risks of rainstorms and floods at UTHM. This study evaluates soil infiltration rates at two selected locations within the University Tun Hussein Onn Malaysia (UTHM). The purpose of this study is to determine the type and gradation of soil and to understand how soil type and vegetation cover influence soil infiltration rates and capacities under varying weather conditions. The study employs the double-ring method to measure and analyze infiltration rates, subsequently generating an infiltration rate curve under different land cover surfaces. The findings revealed that the grass-covered Musolla area had much higher infiltration rates and overall permeability than the bare terrain near the Tunku Tun Aminah Library. On day 1 (a sunny day), the library area had a high initial infiltration rate that gradually decreased, whereas Musolla maintained a consistently high infiltration rate. On day 2 (light rain), the library area experienced a rapid fall in infiltration rate as the soil approached saturation, whereas Musolla maintained a consistent rate supported by grass coverage. On Day 3 (heavy rain), the library area became completely saturated, with almost no infiltration, indicating a high risk of runoff and erosion. In contrast, Musolla maintained strong absorption despite alternating rainy and dry weather. The results highlight the crucial role of vegetation in enhancing soil permeability and managing water, underscoring the importance of grass cover in mitigating soil compaction and improving urban water absorption. The anticipated results will be to support UTHM's commitment to sustainable development and facilitate stormwater management strategies, thereby addressing the challenges posed by urbanization and enhancing the campus's resilience against potential water-related hazards.

1. Introduction

Infiltration refers to the movement of water as it seeps through the uppermost layer of soil. This process has a notable influence on the hydrologic cycle [1]. This downward movement of water wets the soil particles, with the remaining water then descending due to gravitational force, measured in millimeters per second (mm/s) or centimeters per second (cm/s) [2]. Therefore, accurate infiltration tests are crucial for early planning in commercial, residential, or public projects, as they aid in stormwater mitigation by revealing subsurface characteristics. Additionally, estimating cumulative infiltration rates is crucial for predicting water volume and distribution within the soil, which is influenced by factors such as soil depth, geomorphology, hydraulic parameters, and rainfall [3]. Furthermore, the infiltration rate fluctuates depending on the soil's capacity and porosity. This is because soils such as sand have wider pores, which allow for greater penetration; in contrast, clay soils with smaller holes show reduced infiltration rates [4].

Urbanization impacts impervious areas, altering the urban water cycle and increasing runoff and flood risks [5]. This is happening on the UTHM campus, where rapid development has transformed previous surfaces into impermeable layers, increasing runoff and reducing the water available for evaporation [6]. Despite stormwater drains, the 2006 floods at UTHM highlighted infrastructure inadequacies. Persistent flooding or potential water shortages threaten the university's reliance on insufficient water management practices, affecting its sustainability and reputation as a green university [7]. Thus, effective urban runoff management is crucial for protecting urban hydrology and maintaining environmental quality [8].

The objectives of this study are to determine the type of soil and infiltration rates under different climates and plot the infiltration curve at UTHM. This study aims to narrow the knowledge gaps in infiltration rates at UTHM. It also provides benefits in stormwater management and environmental conservation plans, supporting UTHM's sustainability initiatives and protecting water quality while assessing flood risk.

Infiltration plays a pivotal role in dividing precipitation into distinct components within the hydrologic cycle [9]. This process results in water being absorbed by the soil, with subsequent pathways leading either to return to the stream through evaporative processes or groundwater movement or as surface runoff to the sea via stream channels and overland flow.. Moreover, infiltration is also crucial to the concept of water balance, especially in the analysis of runoff, groundwater replenishment, and water conservation. When the soil feature is not a limiting factor, and the application rate is much lower than the infiltration capacity, the irrigation system design should specify the uniformity of water applied [10].

Furthermore, the infiltration rate curve is a graphical representation that illustrates the relationship between the rate at which water is absorbed into the soil (infiltration rate) and the passage of time. The infiltration rate is quantified in units of millimeters per hour (mm/hr) or centimeters per hour (cm/hr) [11]. The relationship between the infiltration rate and time is inversely proportional. The infiltration rate is a crucial factor for both natural and artificial groundwater replenishment, and it is affected by the quality of the soil water.

In soil hydrology, infiltration rate and infiltration capacity are two closely related concepts. The infiltration rate is the rate at which water enters the soil, which is high initially but decreases as the soil becomes saturated. In contrast, the infiltration capacity is the maximum rate at which soil can absorb water when it is fully saturated. The infiltration rate curve illustrates this relationship, with the rate initially high and then leveling off to reach the infiltration capacity, demonstrating the soil's ability to manage water intake over time.

Soil structure, or the organization of soil particles into aggregates, affects water infiltration. The initial and steady-state infiltration rates, which are indicators of soil permeability, are determined based on the physical features of the soil [12]. This is because soil texture, comprising proportions of clay, silt, and sand, significantly influences infiltration rates, with sandy soil allowing for quicker water flow than clayey soil [13]. However, as soil moisture content rises, infiltration rates decrease, which is regulated by factors such as irrigation, plant water intake, and vegetative cover. In comparison, dry soils with pores and fissures will allow water to permeate quickly [2]. Therefore, soil texture and moisture content have a significant impact on infiltration rates due to changes in pore size and the speed of water movement through the soil.

Conservation approaches, such as the use of cover crops, no-till farming, and soil amendments, have a significant impact on soil structure. The presence of vegetation had a more significant impact on the ability of water to seep into the soil compared to soil tillage. This highlights the importance of factors such as the type, density, and condition of vegetation in affecting the rate at which water infiltrates the soil.

Rainfall intensity is a crucial factor influencing infiltration rates, particularly in arid regions where intense and irregular downpours result in brief periods of excessive soil moisture and surface runoff, thereby increasing the risk of flooding [15]. The rate of infiltration increases with the intensity of rainfall until the soil becomes saturated. This saturation is regulated by the movement of water and the soil's properties. However, the duration of rainfall is also important since infiltration slows when the soil becomes saturated [16].

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2. Methodology

2.1 Site Locations

The in-situ measurement was carried out at two locations, which are the Musolla area (Fig. 1 (b)) and the Tunku Tun Aminah library area (Fig. 1 (b)), as shown in the plan area of UTHM in Fig. 1. The Musolla and library areas are marked by blue and green boxes, respectively.

(a)

(b)

(c)

Fig. 1 *Site locations of study (a) Plan area of UTHM; (b) Musolla area (near to Block D1); (c) Tunku Tun Aminah library area*

2.2 Methods and Equipment

A double ring infiltrometer was used to perform the infiltration test at the site locations. The double-ring infiltrometer measures soil infiltration rates using two concentric steel rings. The outer ring prevents lateral water movement and ensures vertical infiltration measurement within the inner ring [20]. In contrast, the single-ring infiltrometer is a cost-effective tool for assessing hydraulic characteristics of soil and field infiltration processes. [1]. Both methods are useful for investigating soil infiltration; however, the double-ring method provides more accurate control of water movement during testing. Fig. 2 (a) shows the equipment used in the infiltration test, which is a double ring infiltrometer, driving plate, hammer, and stopwatch.

Meanwhile, Fig 2 (b) shows sieve analysis test equipment that is used to determine the particle size distribution of granular materials. The essential equipment includes sieves, a sieve shaker, a weighing scale, an oven, and a brush, all of which are crucial for conducting accurate sieve analysis tests. The equipment required for investigating water infiltration into sand, silt, and clay at field capacity [13].

(a) (b)

Fig. 2 *(a) Equipment for sieve analysis (b) Equipment for infiltration test*

2.3 Procedure

The in-situ measurement for the infiltration test was conducted by following ASTM D3385-09: Standard Test Method for Infiltration Rate of Soils in the Field Using Double-Ring Infiltrator. Meanwhile, sieve analysis followed the standard ASTM C136-06: Standard test method for sieve analysis of fine and coarse aggregates.

2.4 Data Analysis

The sieve analysis was performed to determine grain size distribution. The properties of the particle-sized distribution are only quantified in a few discrete size ranges by the sieve analysis; no grading information can be derived between the size intervals [18]. The geometric features of a grading curve describe the specific soil type. The particle size distribution curve obtained from this data allowed for the calculation of the coefficient of uniformity (Cu) using the Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System-ASTM D2487-17).

$$Cu = \frac{D_{60}}{D_{10}} \quad (1)$$

where,
Cu = uniformity coefficient
D_{60} = Diameter that represents a 60% reduction in grain size dispersion fineness.
D_{10} = The effective size is the diameter of the grain size distribution that corresponds to a 10% finer grain.

A sand (fine aggregate) is classified as Poorly Graded (P) if the Cu value is less than 6 (Cu <6) and the fine particle count is less than 5% (fines < 5%). If a sand's fine particle content is less than 5% (fines < 5%) and its Cu value is greater than 6 (Cu ≥ 6), it is classified as Well Graded (W). The coefficient of curvature (Cc) is given by this formula.

$$Cc = \frac{(D_{30})^2}{D_{60} \times D_{10}} \quad (2)$$

A proper grading for soil requires that its Cc value fall between 1 and 3. When considering a single-sized soil mass, Cu and Cc have the same value of 1. The Atterberg limits are used to estimate the ability for engineering materials to swell or contract, and the plastic limit (PL) is frequently employed in agronomy to determine the ideal water content for tillage. The Atterberg limits can be measured using a variety of techniques, each with advantages and disadvantages. Popular techniques for figuring out the liquid limit (LL) include the drop cone penetrometer method (BS 882) and the traditional Casagrande cup method.

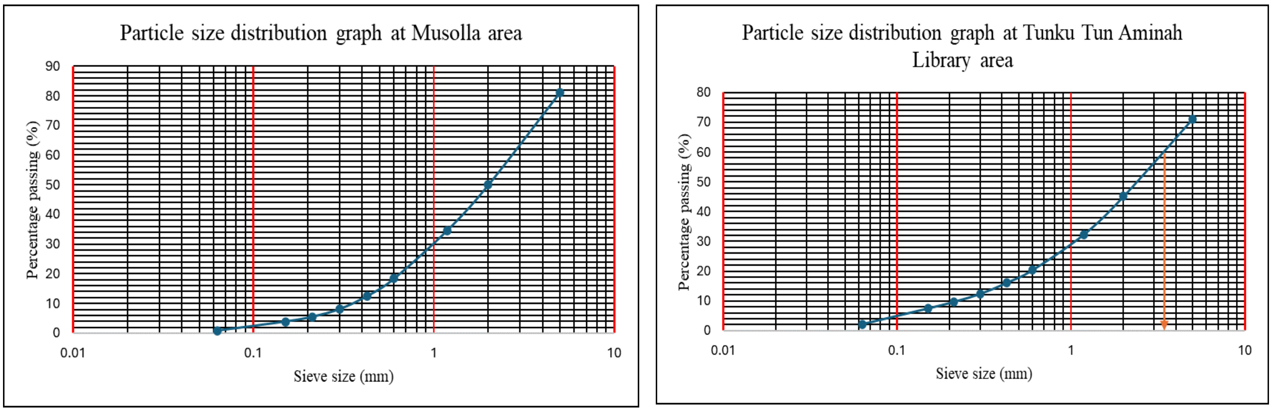
3. Result and Data Analysis

3.1 Particle Size Distribution Graph

Soil samples were collected on February 5, 2024, at the Musolla and Tunku Tun Aminah library areas using a disturbed sampling method. Sieve analysis was carried out after the mechanical shaking process. Fig 3 shows the particle size distribution graph for the Musolla and Tunku Tun Aminah library areas.

The particle size distribution graph in Fig. 3 (a) for the Musolla area shows a cumulative percentage passing versus sieve size, indicating soil composition. The curve starts steeply from 0.01 mm to 0.1 mm, indicating a high proportion of fine particles, such as silts and clays. It then gradually rises from 0.1 mm to 1 mm, indicating the presence of fine sand, and flattens out from 1 mm to 10 mm, showing fewer larger particles such as coarse sand and gravel. This well-graded soil mixture enhances both stability and permeability, making it relevant for both agricultural and construction applications.

Meanwhile, particle size distribution graph for the Tunku Tun Aminah library area in fig 3 (b) indicates the cumulative percentage of soil particles passing through various sieve sizes. The curve rises sharply between 0.01 mm and 0.1 mm, showing a significant presence of fine particles such as silt and clay. It then exhibits a gradual slope from 0.1 mm to 1 mm, indicating a mix of finer sands, and flattens out from 1 mm to 10 mm, indicating a decrease in larger particles, such as coarse sand and gravel. This distribution indicates a well-graded soil, which is beneficial for stability and permeability in various applications.



(a) **(b)**

Fig. 3 *Particle size distribution graph at (a) Musolla area; (b) Tunku Tun Aminah library area*

Table 1 tabulates presents D_{10}, D_{30}, and D_{60}, Cu and Cu values for soil samples from the Musolla and Tunku Tun Aminah library areas. D_{10}, D_{30}, and D_{60} represent the particle diameters at which 10%, 30%, and 60% of the sample's mass are finer, respectively, interpolated from Fig 3. Meanwhile, Cu and Cc values were calculated from equations 1 and 2.

At the Musolla area, the soil is well-graded sand with gravel, as the Cu value is greater than 6 for sand, while the Cc value falls within the range of 1 to 3. It shows good gradation, as indicated by the high Cu and Cc values. The soil exhibits good mechanical properties and a variety of particle sizes, as well as better compaction and stability characteristics. The permeability of soil is expected to be moderate, benefiting from its well-graded nature, which can balance adequate drainage. This soil type can create a more porous structure in certain contexts.

At the Tunku Tun Aminah library area, the Cu value is greater than 6 for sand, while the Cc value is 1 to 3. Hence, the soil is classified as well-graded with a wide range of sand and gravel. The soil has a good distribution of intermediate-sized particles. The soil typically has moderate permeability due to varied particle sizes filling voids efficiently. This reduces pore space and can decrease permeability. The higher value of Cu and appropriately ranged Cc values indicate good gradation, contributing to the soil's stability and suitability as a foundation material and drainage layer.

Table 1 *The value of D_{10}, D_{30} and D_{60} that interpolated from Fig 3.*

Area	D_{10}	D_{30}	D_{60}	Cu	Cc
Musolla	0.36mm	1.00mm	2.75mm	7.64	1.01
Tunku Tun Aminah library	0.25mm	1.10mm	3.40mm	13.60	1.42

3.2 Infiltration Curve

Infiltration investigations were conducted three times at two sites under various weather conditions. This comprehensive approach provided a better understanding of how the soil responds to various climates and vegetation types, including both sunny and wet conditions. Fig 4 shows the infiltration rate curve at the Musolla area from Day 1 to Day 3.

Fig. 4(a) depicts the infiltration rate on Day 1 (February 10, 2024) at the Musolla area during sunny conditions. The infiltration rate curve begins with a high initial rate of 1.67 mm/s, reflecting the presence of short grass and well-graded sand-to-gravel particles that create large pore spaces for efficient water infiltration. This high initial rate and subsequent decline indicate high soil permeability, which is beneficial for reducing surface runoff and promoting groundwater recharge. The rate stabilizes at around 0.1 mm/s, indicating sustained moderate permeability. The infiltration capacity gradually decreases from an initial value of around 1.6mm/s, averaging a drop to 1mm over 2-3 minutes as the soil approaches saturation. Furthermore, the sunny climate enhances the soil's ability to absorb water, with sand and gravel particles allowing for efficient water movement, and short grass maintains the soil structure to prevent surface crusting. This high initial infiltration capacity aids groundwater replenishment and reduces surface runoff, indicating that the soil structure remains effective at managing water infiltration throughout the period.

The infiltration test was conducted on Day 2 (February 13, 2024) during a brief morning rain. Fig 4(b) illustrates that the rate at which water infiltrates the soil initially starts at a high value of around 1.70 mm/s but decreases more rapidly due to the existing moisture. Eventually, the infiltration rate stabilizes by 540 seconds. Despite the initial moisture, the soil rapidly absorbs water, indicating high permeability. This property is advantageous for protecting against erosion and discharge during prolonged rainfall. Initially, the infiltration capacity starts at 1.67 mm/s and then increases to approximately 4.6 mm/s, suggesting successful water absorption even after rainfall. The soil's good drainage and porosity prevent saturation, ensuring ongoing absorption, facilitating groundwater recharge, and maintaining healthy soil moisture and vegetation.

On Day 3 (February 15, 2024), the infiltration rate (Fig. 4(c)) was affected by the changing rain and sunshine over the preceding days, starting at a high value of 1.667 mm/s, which reflects good soil permeability with a grass cover. The rate sharply declines to around 0.4 mm/s, then gradually stabilizes at 0.2 mm/s by 720 seconds, indicating that prior moisture led to partial saturation. This initial high rate helps reduce runoff and promote groundwater recharge; however, the sharp decline indicates that the soil quickly reaches its field capacity. The infiltration capacity increases steadily from 1.67 mm/s to 5.08 mm/s over 720 seconds, demonstrating the soil's strong permeability and resilience, with grass cover preventing erosion and compaction. The soil maintains high porosity and adaptability, efficiently managing water input without quick saturation despite fluctuating weather conditions.

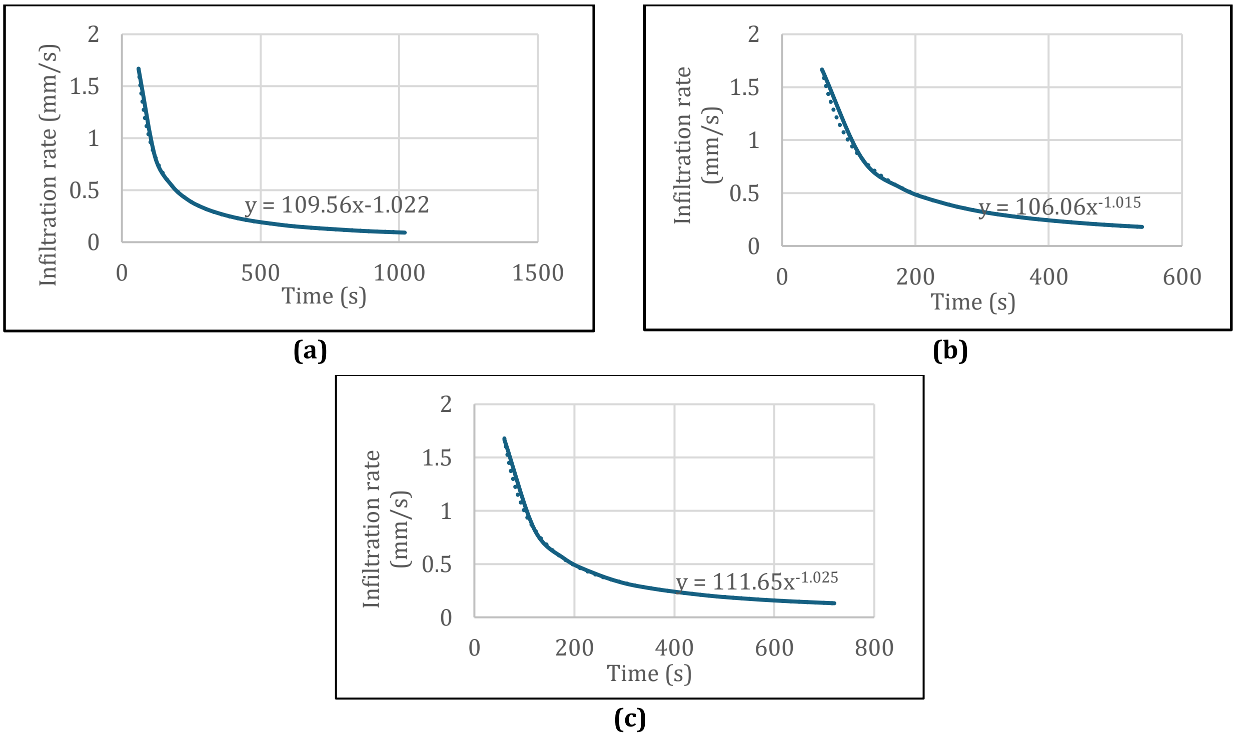


Fig. 4 *Infiltration rate at Musolla on (a) Day 1, (b) Day 2, and (c) Day 3*

Fig. 5 displays the infiltration rate curve for Days 1 and 2 in the Tunku Tun Aminah library area. However, on Day 3, the infiltration rate curve could not be generated because the ground remained consistent in absorbing 8.4 cm of water over an 8-hour period. This suggests that the soil has achieved its maximum capacity for absorbing water, and any more infiltration is negligible. When the circumstances are saturated, the rate at which water enters the soil effectively approaches zero. Excess rainfall will flow off the surface or accumulate in a pond, as the earth has reached its maximum capacity to absorb water. This indicates that the soil's ability to absorb water was fully utilized, resulting in no notable downward movement of water. The saturation was exacerbated by intense precipitation, resulting in surface runoff, heightened erosion hazards, and the possibility of flooding

Fig. 5 (a) shows the infiltration rate on Day 1 at the Tunku Tun Aminah Library. The curve starts high at 1.667mm/s due to dry, permeable soil with large pore spaces, typical of sandy or well-structured loamy soils. The rate rapidly declines within 240 seconds as the soil's absorption capacity is quickly met, then slows and stabilizes at around 0.1mm/s between 900 and 1140 seconds, indicating moderate permeability. The infiltration capacity curve shows an initial high value that rises gradually to 5.47mm/s by 1140 seconds, reflecting the soil's ability to absorb water efficiently despite reaching saturation. This behaviour highlights the soil's physical properties and its capacity to manage water infiltration, with the slowing rate of increase suggesting that it is approaching saturation.

Meanwhile, the infiltration rate on Day 2 starts high at 1.67 mm/s but rapidly declines within the first 100 seconds, stabilizing around 0.3 mm/s after 300 seconds due to prior rain and bare soil conditions. The initial high rate is due to the presence of large soil pores, but the rate drops quickly as the soil becomes saturated. The soil's moderate permeability is evident, with compaction and finer particles, such as silt and clay, slowing water movement. The infiltration capacity starts high but decreases as the soil reaches saturation, reflecting its ability to handle short bursts of heavy rain but reducing its water absorption capacity over time, ultimately reaching 3.81mm/s.

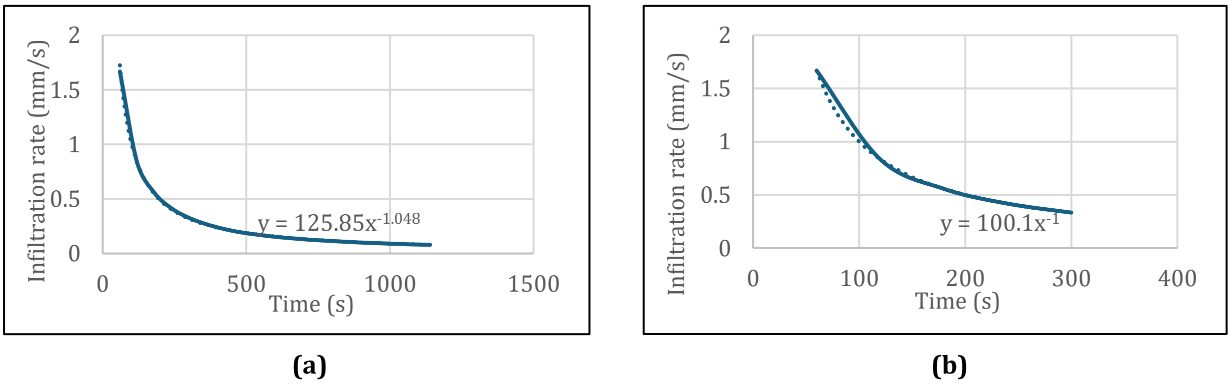


Fig. 5 *Infiltration rate at Tunku Tun Aminah library area on (a) Day 1 and (b) Day 2*

3.3 Summary of Infiltration Characteristics Comparison at Site Locations

The particle size distribution graph highlights the differences in soil properties influenced by vegetation cover, land use, and soil gradation. Table 2 summarizes particle size distribution graph results from site locations.

Table 2 *A summary of particle size distribution graph results from site locations*

Characteristics/ Location	Musolla	Tunku Tun Aminah Library
Land cover	Short grass	Bare land
Gradation	Well-graded	Better well graded in a wider range
Soil Classification	Sand sized particles BS: Fine sand to fine gravel	Higher proportion of gravel BS: Medium sand to fine gravel
Permeability	Higher permeability due to well-graded soil	Slightly lower permeability due to efficient gradation leading to better void filling

Meanwhile, Tables 3 and 4 illustrate the influence of climate factors on soil infiltration characteristics, streamlining the comparison between the Musolla and Tunku Tun Aminah Library areas. The table summarizes soil infiltration characteristics in the Musolla region over three days with varying weather conditions.

Table 3 *Soil infiltration characteristics at the Musolla area*

Day	Weather	Soil Condition	Infiltration Rate	Infiltration Capacity	Comments
1	Sunny	Dry soil with high initial permeability	It starts high and gradually decreases	Steadily increases over time, indicating high capacity	The sunny weather allows the soil to maintain its structure
2	Slow rain in the morning for almost 1 hour before a good sunny climate	Moist soil from recent rainfall, but still drained	Initially high, then decreases at a slower rate	Increases steadily, but very low capacity compared to all days	Even though it was raining slowly, it still had a decent capacity. The short grass aids in preventing erosion and keeping the rate high
3	Changing weather patterns of rain and sunshine for 2 days	Alternating wet and dry conditions, soil remains well-drained	Starts high, consistent gradual decrease	Consistent increase, indicating robust absorption despite changing weather.	Soil handles changing weather conditions well, maintaining high permeability.

Table 4 *Soil infiltration characteristics at Tunku Tun Aminah Library area*

Day	Weather	Soil Condition	Infiltration Rate	Infiltration Capacity	Comments
1	Sunny	Dry	High initial rate, then gradual decrease	High, not reached saturation	Optimal conditions for infiltration; soil can absorb a lot of water initially
2	Raining from the evening on and off	Bare land, partially saturated	High initial rate, and stabilizes	Moderate, soil approaches saturation	Infiltration rate decreases quickly as soil nears saturation due to previous day alternate rain
3	Heavy rain at night	Saturated	Near zero	Fully saturated, constant at 8.4cm before even started to record the rate	Soil has reached maximum capacity, no significant infiltration; high risk of runoff and erosion

4. Conclusion and Recommendation

The infiltration investigation at UTHM reveals distinct differences between the Musolla area and the Tunku Tun Aminah Library area, which are driven by differences in soil composition and vegetation cover. The Musolla area, characterized by well-graded sand-to-gravel soil and short grass cover, demonstrated high permeability across various weather conditions, with effective water absorption and good drainage even after rain. In contrast, the Tunku Tun Aminah Library area, characterized by bare land conditions and a mix of finer particles, including silt and clay, exhibited lower infiltration rates, particularly after rain events, and was more prone to soil erosion and compaction. These findings underscore the importance of vegetation cover and soil composition in influencing infiltration rates and capacities, highlighting the need for targeted soil and water management practices to optimize infiltration and maintain soil health. Enhance vegetation cover in bare land, regular monitoring and maintenance, educational and community involvement are several recommendations can be made to improve soil health, water management, and overall campus sustainability

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting

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